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30 September 1999

ENGINEERING AND DESIGN

Safety and Health Aspects of HTRW Remediation Technologies

ENGINEER MANUAL

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CEMP-RA Engineer Manual 1110-1-4007	Department of the Army U.S. Army Corps of Engineers Washington, DC 20314-1000	EM 1110-1-4007 30 September 1999
	Engineering and Design SAFETY AND HEALTH ASPECTS OF HAZARDOUS, TOXIC, AND RADIOACTIVE WASTE REMEDIATION TECHNOLOGIES	
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Manual
No. 1110-1-4007 — 30 September 1999

Engineering and Design
SAFETY and HEALTH ASPECTS
of
HAZARDOUS, TOXIC, AND RADIOACTIVE WASTE
REMEDIATION TECHNOLOGIES

1. **Purpose.** This manual identifies and analyzes generic safety and health hazards for 25 remediation technologies used in clean-up operations at Hazardous, Toxic, and Radioactive Waste (HTRW) sites throughout the country. This EM is intended for use by U.S. Army Corps of Engineers (USACE) project managers, technical design personnel, and safety and health professionals at all levels, and technical USACE contractor personnel responsible for worker safety and health during all phases of remediation.

2. **Applicability.** This EM applies to all HQUSACE elements and USACE commands responsible for HTRW remediation projects.

3. **References.** References are listed in Appendix A.

4. **Distribution.** Approved for public release, distribution is unlimited.

5. **Discussion.** This manual provides the user with guidance for identifying unique or significant safety and health hazards associated with each of the 25 technologies addressed. Each chapter includes a brief technology description, hazard analysis, and a control point list, designating groups affected by and responsible for the hazards.

Users of this manual are cautioned to utilize the information provided with clear knowledge of specific project requirements and professional judgement. While every attempt has been made to identify hazards of special concern, the manual is not intended to be an all encompassing analyses identifying each and every physical, chemical, radiological, or biological hazard associated with the 25 remediation technologies treated. It is critical for the user, especially those with less professional safety and health training or knowledge, to recognize that the hazard analyses presented in this EM are starting points rather than end points in evaluating the remediation technologies addressed. Each hazard analysis presented must be considered generic and not specific to actual site conditions.

The user of this EM in the end must use all the resources available in identifying project-specific hazards.

FOR THE COMMANDER:

2 Appendices
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Chapter 1
Landfill Covers and Liners

1-1. General.

The technology of landfill liners and covers are discussed briefly in the chapter's first section. The second portion of the chapter contains a hazard analysis with controls and control points listed.

1-2. Technology Description.

Landfills are constructed to contain newly generated wastes or to convert existing waste management units to a permanent disposal facility. Landfills are constructed using liners and covers to minimize exposure of the landfill contents to the environment. Liners and covers are described in this section.

a. Liners.

Types of liners, components of a liner system, and installation methods are described below.

Landfills are lined on the bottom and sides with natural and synthetic barriers to prevent liquids and waste from escaping into underlying soils. An example of a natural liner material is compacted clay; synthetic liners include high-density polyethylene (HDPE), geosynthetic clay (GCL), and polyvinyl chloride (PVC). The synthetic and natural liners are components of an integrated system to contain and collect liquids (leachate) that leach from the landfilled materials.

An example of a typical Resource Conservation and Recovery Act (RCRA) landfill liner includes two liners and a leachate recovery/detection system at the bottom of the waste management unit. A double liner system consists of the following components from top to bottom:

- Leachate collection system (sand and/or gravel).
- Geomembrane.
- Secondary leachate collection/leak detection layer constructed of sand/gravel.
- Secondary synthetic liner.
- Low permeability compacted clay liner.

Monitoring the drainage layer between the liners confirms the integrity of the upper liner.

Clay liners are installed as lifts of a low permeability clay at the appropriate moisture content and density to give the strength and permeability needed for the liner. The lifts are placed until the correct total thickness of the liner is achieved. Nuclear density gauges (with radioactive sources) are often used to estimate the moisture content and density of the clay lifts.

Synthetic liners, such as HDPE, are unrolled from spools and installed as long sheets. They are usually thermal-fusion welded together at the seams. PVC, which can also be used as a liner material, is installed as sheets and is typically seamed by chemical or thermal fusion methods.

As the liner system is installed, leachate collection systems are installed to collect and treat leachate generated by the landfill waste. Leachate is often treated in simple biological or other treatment processes at the site, or is trucked or piped to a local POTW (Publicly Owned Treatment Works) or industrial treatment plant.

b. Covers.

Cover purpose, system components, and installation steps are discussed in this section.

Once the lined landfill is full, an engineered cover is installed. The purpose of the cover is to keep water from infiltrating into the waste materials and generating leachate that could be released from the landfill, while maintaining a protective vegetative cover on top of the landfill to secure the landfilled materials in place. An engineered cover can consist of natural or synthetic materials, or a combination of the two.

The cover system consists of the following components from bottom to top:
- Low permeability liner to prevent water infiltration
- Sand or geonet to provide a drainage layer
- Protective soil cover
- Top soil
- Vegetative cover

Typical cover installation steps include the following:
- Prior to installing an engineered cover, the surface of the landfill is contoured to enhance water runoff. This may involve regrading refuse in the landfill to minimize waste volumes and to ensure positive drainage.
- The low permeability liner is installed on top of the waste materials.
- A layer of coarse sand or a geonet drainage layer is then placed over the liner to collect and transport the water off the surface of the landfill cover.
- A protective soil layer is added to protect the underlying cover components and support vegetative growth.

- As the landfill cover is installed, gas collection and venting systems are installed to manage the gas (methane, hydrogen sulfide, etc.) often produced in landfills. Figure 1-1 illustrates the landfill cover and liner structure.

If the gas is not collected, it can cause heaving and damage the cover, change drainage patterns, and/or it can escape the landfill and migrate to basements and buildings where it may be toxic, explosive, and/or asphyxiating. Gas migration is controlled by providing migration pathways and cover vents.

Off gases can be treated in several ways. If permitted, the most common treatment is simple venting, either passive (by gas pressure generated in the landfill) or active (by vacuum blower assistance to pull gas from the landfill). If simple venting is not acceptable, the gas may be passively or actively vented to a flare. In some cases, the gas is burned in engines or turbines, which may (in turn) drive generators for local power use or feed into the local electrical utility grids.

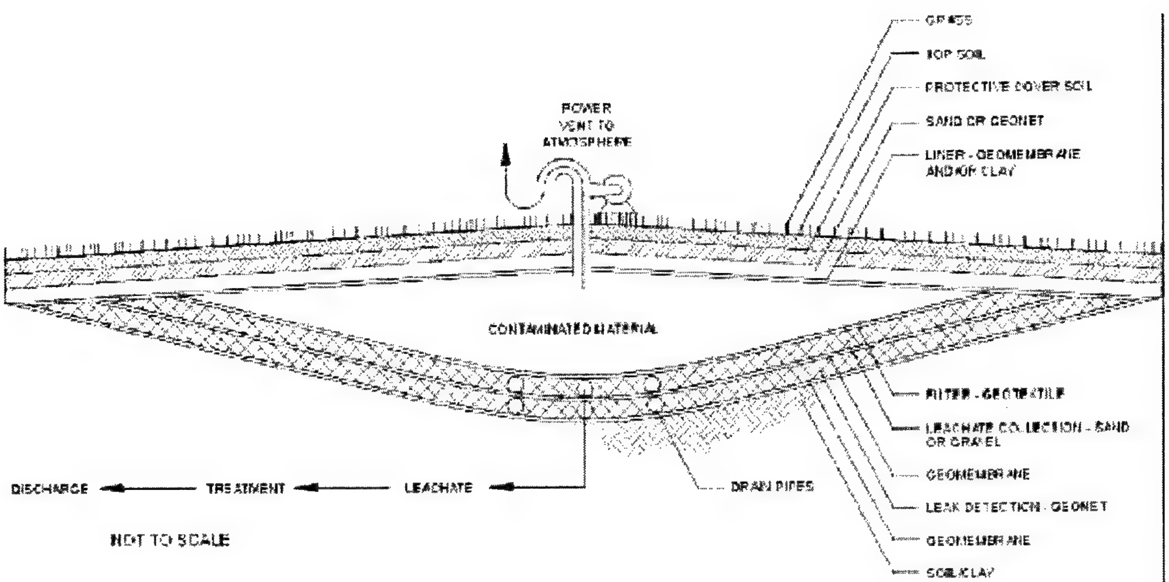


FIGURE 1-1. LANDFILL COVERS/LINERS

1-3. Hazard Analysis.

Principal unique hazards associated with landfill covers and liners, methods for control, and control points are described below.

a. Physical Hazards.

(1) Wind.
Description: Landfill covers/liners installed during periods of high winds may pose trip hazards and/or throw or knock down workers holding or standing on or near unsecured liners.

- Control: Controls for wind hazards include
- Select an appropriate liner material.
- Install liners on calm days.
- Place soil or sand bags onto the unrolled portion of the liner. The liner installer should determine the temporary anchoring needs at the time of installation and ensure that anchoring specifications are met or exceeded.

CONTROL POINT: Design, Construction, Operations, Maintenance

(2) Slip Hazards.
Description: Geomembrane and wet clay liners can be very slippery, especially when placed on the slopes or used for footing while a worker carries equipment or materials.

Control: Controls for slip hazards include
- Consider controls for slip hazards during design (see EM 385-1-1, Section 21.A).
- Use rope ladders for ascending/descending lined slopes.
- Select appropriate shoe soles for maximum traction.
- Lay high-traction walkways over the liners.
- Carry light loads or use more workers to carry larger single loads.

CONTROL POINT: Design, Construction, Operations, Maintenance

(3) Sharp Liner Edges.
Description: Synthetic liners are made in varying thicknesses and rigidities. Some liner edges are sharp and stiff after cutting to shape and can inflict cuts and abrasions.

Control: Controls for sharp liners include
- Wear long-sleeved shirts, full-length pants, and appropriate work gloves (e.g., leather or leather-palmed) for better grip and protection.

- Wear safety glasses or goggles to help prevent eye injuries.

CONTROL POINT: Construction, Operations, Maintenance

(4) Heat Stress.
Description: Heat stress may affect workers during operations. Because most synthetic cover/liner materials are dark or black to enhance ultraviolet (UV) resistance, they absorb radiant energy and emit considerable heat. The surfaces of cover/liner materials can also reflect considerable angled radiant energy, amplifying the energy absorbed by the worker even when wearing a hat. Hot and humid conditions, combined with such operations as liner welding or other heat-producing activities, may also increase the potential for a heat-related illness, including heat exhaustion and heat stroke.

Control: Controls for heat stress include

- Wear hats and wick clothing.
- Provide water to replace body fluids.
- Take frequent breaks under canopies and/or in shaded areas.
- Prohibiting alcoholic beverages.
- Provide ventilation.
- Additional measures include working nights, working early and late in the day, and scheduling jobs for cooler times of the year.

CONTROL POINT: Design, Construction, Operations

(5) Muscle Injuries.
Description: Manual lifting and moving heavy materials used for anchoring may expose workers to muscle strain/sprain to the lower back and/or shoulder.

Control: A control for muscle strain includes

- Use mechanical lifting equipment, such as cranes, backhoes with cables, and spreaders to lift and move liner material.

CONTROL POINT: Construction, Operations

(6) Burn Hazards.
Description: Equipment, including hot-shoe welders and extrusion welders, can expose workers to burn hazards. Flare systems for the discharge of off gas from the landfill and generators may also pose burn hazards.

Control: Controls for burn hazards include

- Make sure all personnel using welding equipment are trained and experienced in the proper use of hot-shoe welding equipment.
- Inform those using or exposed to hot operating equipment at the start of the project and during daily health and safety meetings about equipment hazards.

- Guard all exposed, heated surfaces when practical to prevent accidental contact.
- Request manufacturer's and/or installer's procedures for the safe operation, repair, and maintenance of this equipment and include it in health and safety and installation work plans.
- Use insulated gloves with gauntlets, coveralls, and face protection if necessary.

CONTROL POINT: Construction, Operations

(7) Fire and Explosion Hazards.
Description: Fire and explosion hazards may exist if the off-gas flare systems are improperly designed, installed, or maintained. Also, volatile organic compounds (VOCs) may be generated as off-gas products from wastes in the landfill and accumulate. These gases are explosive and may be ignited as off-gas products by sparks, open flame, or heated surfaces.

Control: Controls for fire and explosion hazards include
- Design and install an off-gas management system using the guidance provided in the EPA Document: EPA/625/4-89/022, Requirements of Hazardous Waste Landfill Design, Construction and Closure.
- Install gas collection and vent systems into the cover. Unless properly vented, the lateral migration of gas should be anticipated.

CONTROL POINT: Design, Construction, Operations, Maintenance

(8) Elevated Gas Levels.
Description: Off-gas drive engines may generate carbon monoxide and carbon dioxide during operation. Also, VOCs generated as off-gas products by landfill wastes may accumulate. If the gases are not properly vented, they may accumulate to hazardous levels in areas such as buildings and sheds. Exposure to elevated levels of these gases may cause headaches, dizziness, nausea, or possibly even death.

Control: Controls for elevated gas levels include
- Specify (landfill designer) the ventilation/flaring requirements necessary to ensure adequate venting of off gases from beneath landfill covers and prevent the potential accumulation of gases migrating into nearby buildings or other structures on or off site.
- Ventilate buildings or other enclosed-space and test to prevent accumulations of carbon monoxide, carbon dioxide, methane, hydrogen sulfide, and other dangerous gases.

CONTROL POINT: Design, Construction, Operations, Maintenance

(9) Electric Shock Hazards.

Description: Electric shock hazards may exist from on-site generators/infrastructure. Generators may be present during construction, operations (off-gas dependent generation), or maintenance.

Control: Controls for electric shock hazards include

- Verify that the hazardous area classifications, as defined in National Fire Protection Association (NFPA) 70-500-1 through 500-10, are indicated on the drawings.
- Verify that all controls, wiring, and equipment, including the on-site generators/infrastructure conform to the requirements of EM 385-1-1, Section 11.G and NFPA 70 for the identified hazard areas.
- Make sure that equipment is grounded and/or provided with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1, Section 11 or NFPA 70 requirements.
- Permit only trained and experienced workers to work on the systems.
- Include appropriate lockout/tagout procedures in the construction and O&M of the system.
- Make fire extinguishers rated for energized electrical systems readily available where electrical equipment is installed and operated.

CONTROL POINT: Design, Construction, Operations, Maintenance

(10) Noise Hazards.
Description: Heavy equipment and portable electric generators may create noise hazards to operators or workers in the immediate vicinity.

Control: A control for noise hazards include

- Wear hearing protection if exposed to noise at or above 85 decibels (steady-state) or to impulse noise of 140 decibels such as that generated by heavy construction equipment or generators.

CONTROL POINT: Construction, Operations, Maintenance

(11) Equipment Hazards.
Description: Any equipment (small and large) used to move soil and liner materials on steep slopes may roll over, crushing the operator.

Control: Controls for equipment hazards include

- Design the angle of the slope to minimize the potential for roll-over.
- Maintain safe slopes during construction (construction contractor).
- Use equipment with roll-over protective devices (ROPS).
- Do not operate equipment on excessively steep slopes.
- Wear seat belts during operation.

CONTROL POINT: Design, Construction, Operations

(12) Traffic Hazards—Worker.
Description: During construction, heavy vehicular traffic may also pose a danger to site workers. The movement of heavy equipment in high traffic areas or public roads may further pose a danger to site workers or to the public.

Control: Controls for traffic hazards include

- Address haul road considerations in the design stage (see EM 385-1-1, Section 21.I for control measures).
- Use warning devices where equipment must cross over active roads according to the criteria of the Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways.

CONTROL POINT: Design, Construction, Operations, Maintenance

(13) Trench Hazards.
Description: During installation of the liner, trenches may be excavated to secure the liner edges. Open excavations may pose a trip hazard to workers crossing the excavation or a collapse hazard to workers working near trench edges.

Control: Controls for trench hazards include

- Provide protection to prevent personnel, vehicles, and equipment from falling into excavations.
- Inform all workers of on-site hazards and allowable access to the landfill.
- See EM 385-1-1, Section 25.B for additional control measures and requirements.

CONTROL POINT: Construction, Operations, Maintenance

(14) Heavy Equipment Hazards.
Description: Workers may be seriously injured or killed by the operation of heavy equipment moving liners and other materials. As liners are unrolled, workers may be injured if the liner is allowed to unroll down a working slope of a landfill.

Control: Controls for heavy equipment include

- Use earth-moving equipment and trucks equipped with a backup alarm that alerts workers.
- Approach operating equipment from the front and always within view of the operator.
- Develop an alarm communication system to warn workers during liner unrolling activities, as necessary.

CONTROL POINT: Construction, Operations, Maintenance

(15) Steam Pressure Washing Hazards.
Description: Steam pressure washing of equipment may expose workers to thermal or burn hazards, eye hazards due to flying projectiles dislodged during washing, slip hazards from wet surfaces, and noise hazards.

Control: Controls for steam pressure washing include

- Use insulated gloves (e.g., silica fabric gloves).
- Use safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from decontamination operations into a tank or pit. Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(16) Respirable Quartz Hazard.
Description: Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422, followed by analysis of the fines by X-ray diffraction to determine fine material quartz content.

Control: Controls for respirable quarts include

- Wet soil periodically with water to minimize worker exposure. Wetting of soil may require additional controls to deal with resulting water, ice, mud, etc.
- Use respiratory protection, such as an air purifying respirator equipped with a HEPA (N100, R100, P100) filter/cartridge.

CONTROL POINT: Design, Construction, Operations, Maintenance

(17) Ultraviolet (UV) Radiation.
Description: During site activities, workers may be exposed to direct and indirect sunlight and the corresponding UV radiation. Even short-term exposure to sunlight can cause burns and dermal damage.

Control: Controls for UV radiation include

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen.
- Shade work and break areas if possible.

CONTROL POINT: Construction, Operations

(18) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

(19) Traffic Hazards.
Description: The general public may be exposed to traffic hazards and the potential for accidents during loading and transporting soil from borrow pits to the landfill.

Control: A control for traffic hazards to the general public includes

- Develop a traffic management plan before excavation activities commence to help prevent accidents involving dump trucks and automobiles. EM 385-1-1, Section 21.I10 provides plan details.

CONTROL POINT: Design, Construction, Operations

(20) Utility Contact Hazards.
Description: Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control: Controls for utility contact hazards include

- Locate overhead power lines, either existing or proposed, in the pre-design phase.
- Keep all lifting equipment, such as cranes, forklifts, and drilling rigs at least 10 feet from a power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.E.

CONTROL POINT: Design, Construction, Operations

(21) Explosion Hazards.
Description: During excavation activities, workers may be exposed to explosion hazards associated with unexploded ordnance or buried flammable materials at military bases.

Control: Controls for explosion hazards include

- Use metal detectors or ground-penetrating radar prior to excavation to clear the excavation area of such hazards. Hand probes may also be used.
- Excavate soil suspected of containing an underground hazard slowly and with caution.

CONTROL POINT: Design, Construction, Operations

b. Chemical Hazards.

(1) Solvents.
Description: The heating or solvent welding of the cover/liner materials may generate vapors from adhesives, thermal decomposition, and/or outgassing of liner material components such as plasticizers (e.g., phthalate esters, adipate esters), or from any solvents contained in the adhesive (e.g., methyl ethyl ketone, methylene chloride). A dermal hazard may also exist from skin contact with the cementing chemicals and/or waste materials generated during installation.

Control: Controls for solvents include

- Ventilate the area or use appropriate respirators to control exposures during installation. Select respirator cartridges based on consultations with the liner manufacturer(s) and the potential compounds that may be emitted.
- Use personal protective equipment (PPE) such as chemically resistant gloves (e.g., nitrile) to help control dermal exposure.
- Perform an analysis of possible chemical exposures prior to issuing gloves and other PPE. The analysis should include obtaining specific chemical hazard information on the liner constituents.

CONTROL POINT: Construction, Operations, Maintenance

(2) Waste Chemicals.
Description: Workers may be exposed to waste chemicals such as airborne dusts and particulates and VOC emissions resulting from redistribution of wastes associated with liner installation, landfill off gassing, and/or leachate collected by leachate collection and treatment systems. Leachate may contain both organic and inorganic constituents.

Control: Controls for waste chemicals include

- Apply water or an amended water solution to control airborne dust, particulate, and VOCs generation.
- Use respiratory protection including air-purifying respirators equipped with approved filters/cartridges such as HEPA (N100, R100, P100) filters for particulates, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Use PPE to control leachate exposure.
- Conduct an analysis of work tasks and potential chemical exposure, including a chemical waste profile, to determine correct PPE and/or respirator cartridges if necessary.

CONTROL POINT: Construction, Operations, Maintenance

(3) Hazardous Landfill Gases.
Description: Methane generated by existing landfills is highly combustible and is an asphyxiant. The off gas generated from an existing landfill may also contain concentrations of vinyl chloride and hydrogen sulfide. Vinyl chloride is a human carcinogen, and hydrogen sulfide damages lungs and circulation. The hazards from exposure to landfill gas must be considered during predesign, design, construction, operations, and maintenance.

Control: Controls for landfill gases include

- Perform soil gas surveys during pre-design to determine the levels of methane, hydrogen sulfide, and vinyl chloride in soil. The methods for collecting landfill off-gas samples (barhole probe, permanent gas monitoring, and gas extraction wells) are discussed in EPA-450/3-90-011a, Air Emissions From Municipal Solid Waste Landfills.
- Perform periodic monitoring of landfill off gas during construction, especially in enclosed areas such as excavations and other low, undisturbed areas.
- Ventilate an area if methane levels reach 10 percent of the Lower Explosive Limit (LEL).

CONTROL POINT: Design, Construction, Operations

c. Radiological Hazards.

(1) Nuclear Gauge Hazards.
Description: Use of a nuclear gauge to determine the moisture content and density of the clay liner and cover may pose a radiation hazard.

Control: Controls for nuclear gauges include

- Use personnel with the proper training and experience in the use and maintenance of the neutron density gauge.

- Comply with Nuclear Regulatory Commission (NRC) Standards for Protection Against Radiation (10 CFR 20), NRC Rules of General Applicability to Domestic Licensing of Byproduct Material (10 CFR 30), licensing requirements for the particular source (10 CFR 31, 32, or 39), all license conditions, and OSHA 29 CFR 1910.1096 or 29 CFR 1926.53.

CONTROL POINT: Construction, Maintenance

(2) Radioactive Materials.
Description: Although an uncommon hazard, radioactive materials may pose a hazard by exposure to radiation or inhalation/ingestion of radioactive particles during the installation of covers/liners. A variety of radiation sources may have ended up in landfills including Naturally Occurring Radioactive Materials (NORM) from oil and gas exploration and production, medical wastes, low-level research wastes, and disposed instruments and their sources.

Some radioactive materials are pyrophoric. Machine filings or turnings of uranium or thorium may spontaneously ignite, and pose fire and airborne radioactivity hazards. Turnings or filings buried in existing landfills may combust upon excavation when the material is exposed to air. Other radioactive materials may present an external exposure hazard.

Control: Controls for radioactive materials include

- Test the contents of the landfill prior to construction or maintenance operations.
- Consult a qualified health physicist to determine the exposure potential, the nature and extent of the radiation and/or radioactive materials, necessary controls, and the appropriate PPE to prevent exposure.
- Provide decontamination facilities if required, using guidance such as *The Health Physics and Radiological Health Handbook* (Bernard, Schleien, Scinta, Inc. 1992).

CONTROL POINT: Design, Construction, Operations, Maintenance

d. Biological Hazards.

(1) Biological Contaminants.
Description: At those sites involving medical wastes or sewage sludge, biological hazards may result through inhalation/ingestion and/or dermal contact with microbes in the waste and pathogens, such as *Coccidioides sp., Histoplasma sp.,* and *Mycobacterium sp.* Exposure to biological hazards may result in eye and skin bacterial and fungal infections.

Control: Controls for biological contaminants include

- Test the contents of the landfill to assess the potential risk and prevent exposure to dangerous biological materials during construction. If such materials are present, follow the next step.

- Determine the nature and extent of biological materials and the appropriate PPE to prevent exposure and provide decontamination.
- Prevent inhalation/ingestion of biological materials through dust suppression techniques using water or amended water treatments. Use dust suppression techniques only when adequate runoff controls are in place and a slip hazard is not generated from the wetting of the material.
- Control eye infections by using portable eyewashes to remove dust or other objects from the eyes.
- Use germicidal soap prior to eating or drinking.

CONTROL POINT: Design, Construction

(2) Pests.
Description: Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus.

Control: controls for pests include

- Perform periodic inspections of the site to identify bee hives and wasp nests and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents for exposure control. Workers should check their skin and clothing for ticks periodically throughout the workday.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 2
Extraction/Monitoring Wells (Vertical/Horizontal Wells) and Soil Flushing

2-1. General.

In the chapter's first section, extraction/monitoring well components and how they function along with well development techniques are briefly described. Soil flushing methods are also discussed. The second portion of the chapter is a hazard analysis with controls and control points listed.

2-2. Technology Description.

a. Extraction/Monitoring Well Components and Methods.

Extraction/monitoring wells are typically vertical or horizontal PVC, steel, or stainless steel pipes with screened sections to allow groundwater or soil gas to enter the pipe interior. The wells are typically installed into a vadose (unsaturated) zone and/or an aquifer at strategic locations to extract or monitor groundwater or soil gas. The pipe is installed into a slightly oversized borehole, typically created by using a hollow stem auger drilling rig. Air and mud rotary methods may be used to install deeper wells. The annular space between pipe and boreholes, where the pipe is screened, is typically surrounded with a porous sand or other packing to filter out larger particles as water/air enters the well. The boring outside the well pipe, above the filter pack (above the screened well section) is typically sealed with cement or bentonite slurry to prevent mixing of groundwater/air from above the screened zone with water or air entering the well down the boring and above the filter pack.

A down-hole pump (electrical or air driven) is typically used for water extraction wells to move the contaminated water to the surface. A surface vacuum pump (positive displacement, centrifugal, or regenerative depending on air flow, soil formations, and other factors) is used for air extraction. Water is usually extracted from monitoring wells using manual bailers, peristaltic, or similar pumps that may or may not be dedicated to each well.

Small "alpha" type air pumps feeding tedlar bags are typically used for air monitoring wells to extract samples through a well cap nipple, or through a small tube inserted through the well cap and down the barrel of the well. The extracted water/air may then be analyzed (monitoring wells) or treated (extraction wells) with above-ground treatment technologies. A schematic of a typical vertical extraction/monitoring well is presented in Figure 2-1. Once installed, the wells are developed by surging water along the well, jetting, pumping, bailing or air sparging (on and off) to remove drilling mud, silt, and cutting materials. The procedure allows free flowing water/air into the well.

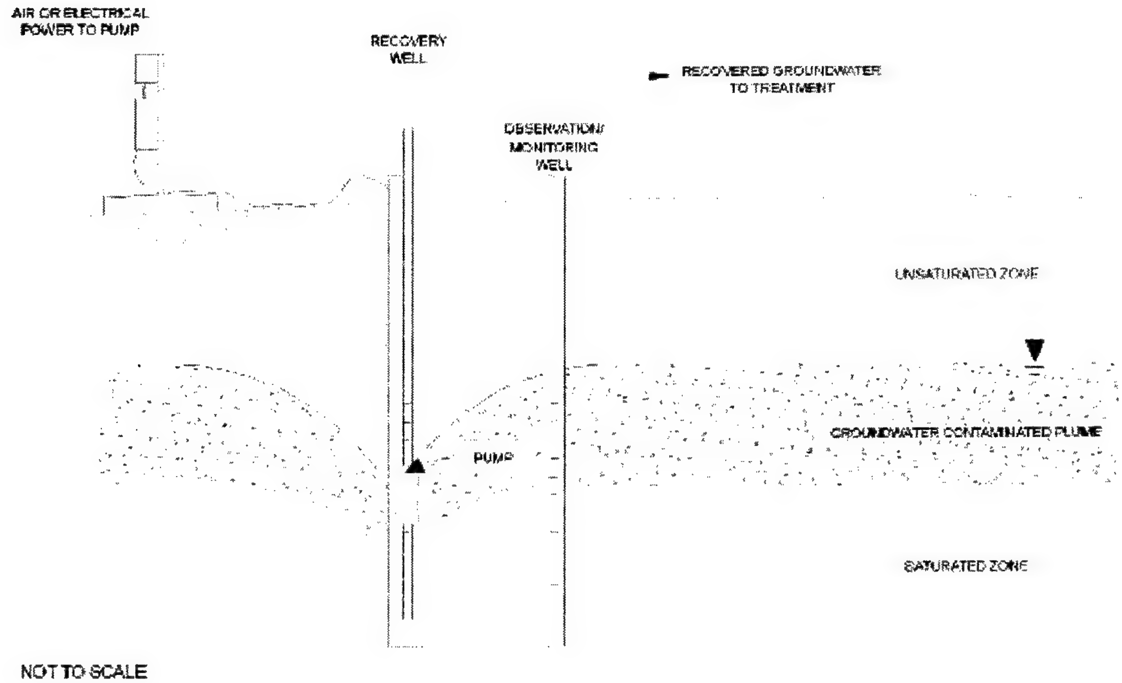


FIGURE 2-1. VERTICAL EXTRACTION WELL

An alternative to vertical extraction wells is horizontal extraction of water/air through wells installed using either a drill rig designed to slant or curve the boring or temporary trenches to install the well pipe at a horizontal orientation. Horizontal wells offer a greatly enhanced capture zone since a long horizontal length of the well can be screened and filter packed, while vertical wells' screened lengths are limited by the depth of the aquifer. Figure 2-2 shows a schematic of a horizontal well.

Extraction wells are the most common water/air recovery technology used for groundwater/soil cleanup in "pump-and-treat" systems and in soil vapor extraction (SVE) systems. The effectiveness of pump-and-treat systems, and hence extraction wells, depends strongly on hydrogeologic properties (e.g., porosity, permeability) and contaminant properties (e.g., volatility, partitioning coefficients).

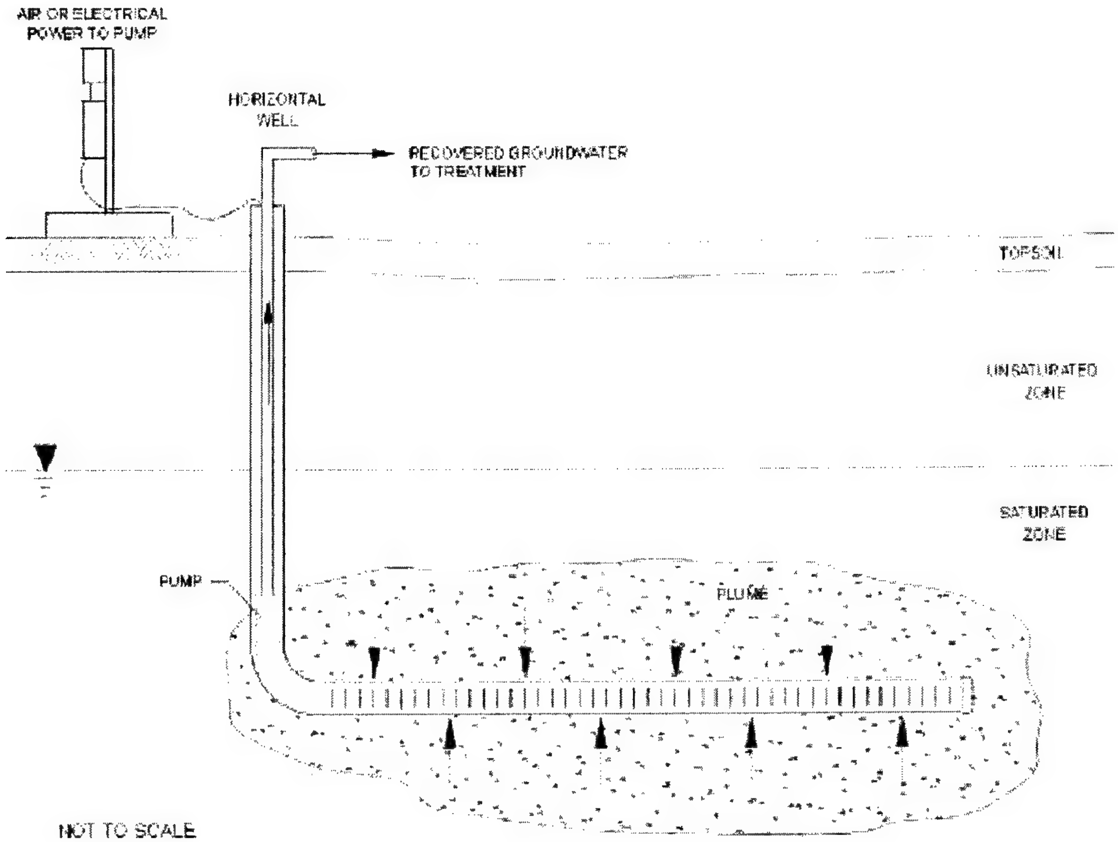


FIGURE 2-2. HORIZONTAL EXTRACTION WELL

b. Well Development Techniques.

When the performance of wells declines, they are often cleaned and redeveloped using some of the well development processes discussed below under Soil Flushing Methods, but may also be rehabilitated via additional processes. The additional processes may include

- Acidification (e.g., hydrofluoric, sulfamic, or hydrochloric acids) to chemically react with and remove acid-soluble scales and hydrolyze biofouling.
- Hypochlorite or peroxidation to kill and hydrolyze biofouling.
- Mechanical scrubbing or swabbing to clean scale and biofouling.

Wells may also be redeveloped using standard development techniques, such as surging, to remove accumulated fines and sediments and rejuvenate well performance.

c. Soil Flushing Methods.

Soil flushing is a technology also linked to pump-and-treat methods (Figure 2-3). Water, with or without additives (such as surfactants) to enhance the removal of contaminants, is pumped through or infiltrated through contaminated soils to flush (in-situ wash) contaminants into the groundwater for collection by groundwater extraction wells and treatment. If enhancers are added, typical additives are surfactants that act as detergents, change interfacial tensions between the soil/water/contaminants, and form micelles, thus enclosing contaminants and enhancing the rate of contaminant removal and recovery. To flush material from soils into the groundwater requires that groundwater be captured, extracted and treated, or that the groundwater be treated *in-situ* to prevent further areal spread of contamination. Soil flushing is a remediation enhancement that is infrequently employed.

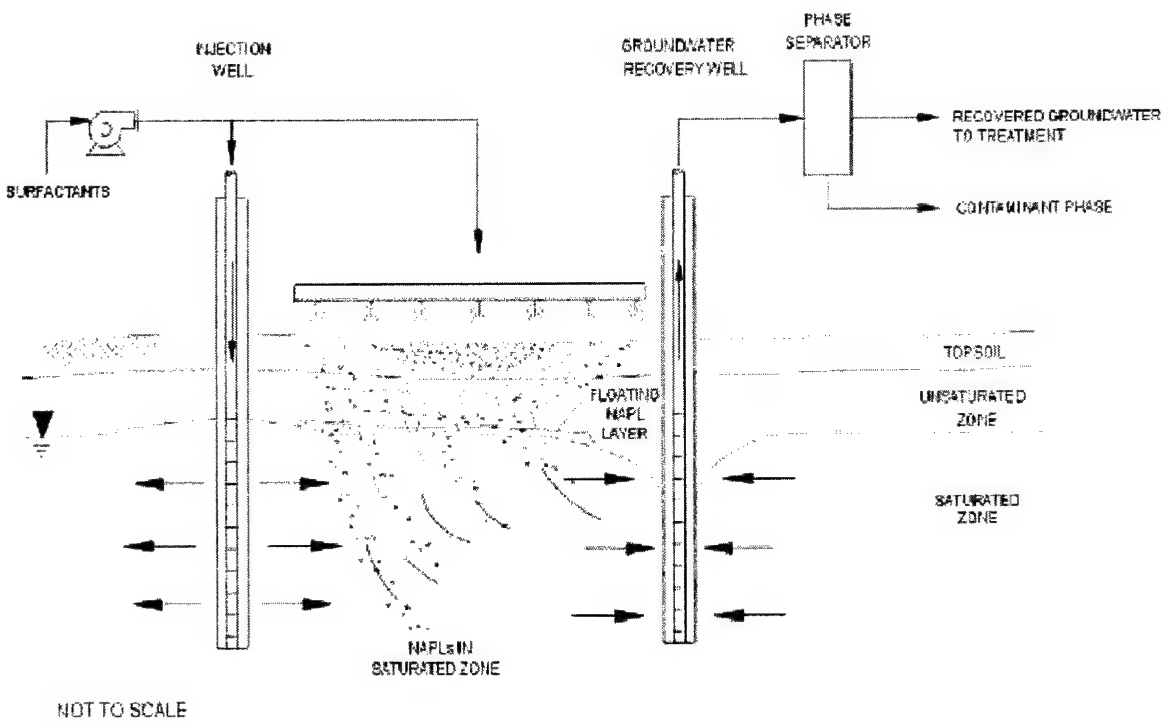


FIGURE 2-3. SOIL FLUSHING

2-3. Hazard Analysis.

Principal unique hazards associated with extraction/monitoring wells (vertical/horizontal wells) and soil flushing, methods for control, and control point are described below.

a. Physical Hazards.

(1) Equipment Hazards.
Description: During drilling operations, heavy equipment such as augers, cables, buckets, and pipes are periodically raised overhead and placed into or above the well. Thus, workers may be exposed to swinging equipment during lifting, or may be exposed to crushing hazards if equipment falls or is carelessly lowered. Loose clothing may become entangled in cables used to raise and lower equipment or on the equipment itself. Lowered augers, buckets, or direct push drilling methods (using hydraulic pressure to advance a soil boring) may further pose a crushing hazard to hands or feet. Rough edges or spaces on cables, auger flights, buckets, and pipe may cause cuts and abrasions.

Controls for equipment hazards include
- Establish a work zone around the drilling rig and permit only those personnel and equipment required for the task within the zone.
- Inspect lifting equipment regularly and operate it safely.
- Raise equipment only as high as needed.
- Maintain contact with the raised equipment to help minimize swinging.
- Wear appropriate clothing and equipment (site workers). (Avoid wearing loose clothing.)
- Avoid contact with auger edges, running cables, and pipe; wear work gloves to prevent cuts and abrasions from exposed spurs, wires, and edges. No jewelry should be worn (operators).

CONTROL POINT: Construction, Maintenance

(2) Rotating Equipment.
Description: The rotating auger and other rotating or moving parts, such as "cat heads" and winches, pose a potential hazard to workers if loose clothing becomes entangled with the revolving equipment.

Control: Controls for rotating equipment include
- Secure all loose clothing and remove jewelry.
- Use low-profile auger pins and long-handled shovels to remove soil cuttings from the borehole.
- Use cable systems with caution and inspect regularly for loose strands or frayed wires that may become entangled in loose clothing.
- Use drilling equipment equipped with a cut-off switch accessible to all drill crew members.

- Train operators on safe drilling practices.

CONTROL POINT: Construction, Maintenance

(3) Utility Contact Hazards.
Description: Fire, explosion and/or electrocution hazards may exist when using hollow-stemmed auger, direct push, or other drilling methods if the drilling mast or auger comes in contact with overhead electric lines, or ruptures underground utilities or tank/piping systems.

Control: Controls for utility contact hazards include

- Identify the location of all below- and above-ground utilities prior to drilling by contacting local utilities and public works personnel.
- Use a metal detector to help detect buried metal piping. When there is any doubt or uncertainty, probe with a metal rod prior to excavation or hand excavate to determine the exact location of utilities prior to drilling. Once utilities are located, careful excavation by backhoe may be allowed.
- Have an observer to the side to observe and guide when raising a drill mast.
- Operate the mast at its lowest height; different drill rigs will have different mast elevations and may be operated at different heights.
- Do not move the drilling rig with the mast raised.
- Locate overhead hazards and design so that installations using erect equipment are not necessary in that area, if possible.

CONTROL POINT: Design, Construction

(4) Flammable or Combustible Material.
Description: Soil boring using hollow-stemmed augers or other drilling methods may cause a fire or explosion in soils saturated with flammable or combustible materials under unusual or extraordinary conditions. Sparks generated when an auger contacts rocks, metal, or other underground objects may ignite a flammable atmosphere inside the bore hole. Examples of materials particularly subject to ignition in this manner are carbon disulfide (CS_2), methane, natural gas, ethane, propane, ethylene, benzene, or hydrogen sulfide, a decomposition product.

Control: Controls for flammable/combustible materials include

- Use methods such as mud or water rotary drilling when drilling in areas suspected to contain soils saturated with flammable or combustible materials. These methods add moisture to the cutting area unlike hollow-stem augers.

CONTROL POINT: Design, Construction

(5) Electrical Fires or Explosions.
Description: Electricity in a wet environment and in the presence of flammable, floating layers of explosive NAPL may cause a fire or explosion.

Control: Controls for electrical fires include

- Verify that the hazardous area classifications, as defined in NFPA 70-500-1 through 500-10, are indicated on the drawings.
- Verify that all controls, wiring, and equipment conforms with the requirements of EM 385-1-1, Section 11.G and NFPA 70 for the identified hazard areas.
- Use equipment that is grounded and/or provided with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1, Section 11 or NFPA 70 requirements.
- Permit only trained and experienced workers to work on the systems.
- Include appropriate lockout/tagout equipment and procedures in the construction and O&M of the system.
- Have fire extinguishers rated for energized electrical systems readily available where electrical equipment is installed and operated.

CONTROL POINT: Design, Construction, Operations, Maintenance

(6) Extraction of Flammable Liquids.
Description: Extraction of flammable liquids may cause a fire if the material is ignited via extraction, transfer or storage, or if gases vented from the storage tank come in contact with a spark or other source of ignition. Fires may also occur if extraction pumps are not selected and installed in accordance with the appropriate EM 385-1-1, Section 11 and NFPA 70 requirements.

Control: Controls for extraction of flammable liquids include

- Use equipment that is grounded and/or provided with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1, Section 11 or NFPA 70 requirements.
- Direct tank vents to prevent contact with sources of ignition.
- Verify that the hazardous area classifications, as defined in NFPA 70-500-1 through 500-10 are indicated on the drawings.
- Verify that all controls, wiring, and equipment, including the piping system, conforms with the requirements of EM 385-1-1, Section 11.G and NFPA 70 for the identified hazard areas.
- Permit only trained and experienced workers to work on the systems.
- Include appropriate lockout/tagout equipment and procedures in the construction and O&M of the system.
- Have fire extinguishers rated for energized electrical systems readily available where electrical equipment is installed and operated.

CONTROL POINT: Design, Construction, Operations, Maintenance

(7) Steam Pressure Washing.
Description: Steam pressure washing of equipment may expose workers to thermal or burn hazards, eye hazards due to flying projectiles dislodged during washing, slip hazards from wet surfaces, and noise hazards.

Control: Controls for steam pressure washing include
- Use insulated gloves (e.g., silica fabric gloves) to prevent thermal burns.
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(8) Drill Rigs.
Description: Drill rigs can seriously injure workers during positioning for drilling.

Control: Controls for drill rigs include
- Equip drill rigs and other vehicles with a backup alarm that alerts workers to moving vehicles.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.

CONTROL POINT: Construction, Maintenance

(9) UV Radiation.
Description: During site activities, workers may be exposed to direct and indirect sunlight and corresponding UV radiation. Even short-term exposure to sunlight can cause burns and other dermal damage. Exposure to hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control: Controls for UV radiation include
- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen.
- Shade work and break areas if possible.
- Minimize exposure to heat stress by taking frequent breaks, drinking adequate fluids, and performing work during the early morning and late afternoon hours.

CONTROL POINT: Construction, Operations

(10) Muscle Injuries.
Description: Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control: Controls for muscle strain include

- Use mechanical lifting equipment to lift heavy loads.
- Use proper lifting techniques including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385 1-1, Section 14.A). Use two people if necessary for manual lifting.

CONTROL POINT: Design, Construction, Operations, Maintenance

(11) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Contamination Hazards.
Description: Exposure to airborne dusts, VOCs, and metals in contaminated soils and/or groundwater brought to the surface during drilling, soil and groundwater sampling, and infiltration system installation can be hazardous to on-site personnel. During well installation, site workers may be exposed to gasoline, diesel fuel, or other organic materials as well as heavy metals such as lead and chromium. These hazards can be contacted through dermal exposure, ingestion, or vapor inhalation. Workers may also be exposed to reactive, caustic, or acidic materials from cuttings and groundwater.

Control: Controls for chemical contamination hazards include

- Use personal protective equipment (PPE) selected by a qualified health and safety professional (e.g., air-purifying respirators, chemically-resistant disposable coveralls, water/chemical impervious gloves [e.g., nitrile], and rubber or steel-toed leather boots).
- Have frequent health and safety meetings.
- Use experienced workers, decontamination stations, and/or other standard procedures.
- Test soils for reactive, highly flammable, or corrosive materials.
- Design all installation methods appropriately.

- Use non-sparking tools and intrinsically safe equipment in extreme conditions (e.g., carbon disulfide, CS_2) if emissions are expected to be high.
- Conduct personnel and general area monitoring for airborne chemicals when exposures may potentially exceed half of the threshold limit value (TLV) or permissible exposure limit (PEL). Also conduct area monitoring when airborne combustible chemical concentrations exceed 1/10 of the lower explosive limit (LEL).
- Use proper respiratory protection (e.g., air-purifying respirator with filters and/or organic vapor cartridge) if ventilation or other engineering, work practice, or administrative controls are insufficient to maintain exposures less than the TLV or PEL.
- Select respiratory protective equipment in accordance with the OSHA regulation 29 CFR 1910.134 and the National Institute for Occupational Safety and Health (NIOSH) guidelines.

CONTROL POINT: Construction, Maintenance

(2) Additive Hazards.
Description: Additives (usually surfactants used in flushing) enhance exposure to contaminants by increasing dermal absorption and holding contaminants on skin. For example, linear alkyl benzene sulfonate or ethoxylate surfactants could be used to enhance recovery of contaminants as part of a pump-and-treat groundwater extraction program. This could also enhance concentrations of contaminants in the recovered water, increasing the risk and hazard of contact with that water. In addition, additives can increase the solubility of contaminants, raising concentrations to which personnel are exposed.

Control: A control for additive hazards includes

- Select additives (system designer) with the lowest health and safety impact that can still perform the process (e.g., avoid use of materials such as dimethyl sulfoxide [DMSO], which enhances dermal absorption, when other solvents are available and practical).

CONTROL POINT: Design, Operations

(3) Chemical Fire or Explosion.
Description: Fire and/or explosion or chemical release (inhalation/ingestion/asphyxiation) hazards may exist when using hollow-stem auger, direct push, or other drilling methods if drilling ruptures underground utilities or tanks/overhead piping systems that contain hazardous chemicals.

Control: Controls for chemical fire or explosion include

- Perform a utility survey, probe with a metal rod prior to excavation, or hand excavate to determine the exact location of underground lines prior to drilling.
- Develop actions/procedures to locate overhead hazards during design.

CONTROL POINT: Construction

(4) Acids.
Description: Acids used in well flushing or rehabilitation may pose skin, eye, or inhalation hazards upon contact.

Control: Controls for acids include
- Use closed acid injection systems to minimize worker exposure to acids.
- Wear PPE, such as neoprene gloves, chemically-resistant coveralls, safety goggles, and a face shield.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

(1) Equipment.
Description: Use of a neutron or gamma source in down-hole logging systems to log wells may pose a radiation hazard if improperly used or if damaged in such a way as to expose the sources.

Control: Controls for equipment hazards include
- Use personnel with the proper training and experience in the use of neutron density gauges and proper maintenance of the instrument.
- Comply with the Nuclear Regulatory Commission (NRC) Standards for Protection Against Radiation (10 CFR 20), NRC Rules of General Applicability to Domestic Licensing of Byproduct Material (10 CFR 30).
- Note the license type required for the particular source (10 CFR 31, 32, or 39) as well as license conditions and OSHA 1910.1096 or 29 CFR 1926.53 criteria.

CONTROL POINT: Design, Construction, Maintenance

(2) Contaminants.
Description: Contaminants in the groundwater and soil may pose a rare radiation hazard to personnel through inhalation or ingestion of radioactive materials during installation, sampling, and maintenance of wells or well-related systems. Buildup of radioactive scale in the well and associated piping may present an external exposure hazard. Contaminants may include naturally occurring radioactive material (NORM), radium, thorium, and uranium, or radioactive wastes that have been buried in previous disposal activities.

Control: Controls for radioactive contaminants include
- Test the soil and groundwater to determine if elevated levels of radioactive materials are present.
- Consult a qualified health physicist if elevated levels occur to determine the exposure potential and any necessary engineered controls or PPE.

CONTROL POINT: Design, Construction, Maintenance

d. Biological Hazards

(1) Biological Contaminants.
Description: At those sites involving medical wastes or sewage sludge, microorganisms in the groundwater and soil may cause exposure hazards during the installation, sampling, and maintenance of the wells or well-related systems. Workers may be exposed to inhalation/ingestion and/or dermal contact with pathogens, such as *Coccidioides sp., Histoplasma sp.*, and *Mycobacterium sp.* The resulting exposure may result in an occupational illness.

Control: Controls for biological contaminants include

- Test microorganisms in the groundwater and soil and determine the appropriate PPE to prevent exposure. The appropriate PPE typically includes an air-purifying respirator equipped with HEPA (N100, R100, P100) filters/cartridges.
- Enforce (strictly) eating, drinking, and smoking restrictions prior to washing/decontamination. Decontamination with water and or disinfectant soaps may be used to control exposure.
- Wear chemically-resistant protective overalls to prevent clothes from becoming grossly contaminated with wastes, soils, and/or contaminated water. If contaminated clothing is laundered, use a commercial laundry familiar with cleaning procedures for industrial clothing. These procedures include employee hazard warnings and cleaning solution disposal requirements.

CONTROL POINT: Design, Construction

(2) Dangerous Insects or Animals.
Description: Well vaults or enclosures may have snakes, spiders, scorpions or other potentially dangerous insects and animals sheltering or trapped in them that could bite or sting workers during operations or maintenance.

Control: Controls for dangerous insects or animals include

- Design well vaults with tight covers where practical to prevent entry of insects and animals.
- Remove well vault covers with a hook or other tools to prevent possible bites or stings.
- Inspect vaults after opening and prior to entry to determine if snakes, spiders, scorpions, or other potentially dangerous insects and animals are present. If present, the animals should be removed in a safe manner by a qualified health and safety professional.

CONTROL POINT: Design, Operations, Maintenance

(3) Pests.
Description: Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus.

Control: Controls for pests include

- Perform periodic inspections of the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies for removal.
- Use tick and insect repellents for exposure control. Workers should check their skin and clothing periodically throughout the work day.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 3
Excavation, Removal, and Off-Site Disposal

3-1. General.

The process of excavation of contaminated solids/sludges, dewatering, pretreatment, and technology applications are briefly discussed in the first section of the chapter. The second portion of the chapter is a hazard analysis with controls and control points listed.

3-2. Technology Description.

a. Process.

Contaminated solids/sludges are excavated, dredged, or pumped from surface or subsurface areas, typically staged for loading (treated if required), and loaded into transport vehicles for shipment to an approved receiving facility (usually a licensed landfill). Soils can be excavated with backhoes, front loaders, continuous excavators, scrapers or other equipment. Sludges can be removed with open-face (impeller) centrifugal pumps, backhoes, or similar equipment. Submerged sediments are often removed using a dredge.

Material may be dewatered during staging operations. Dewatering, if needed, can be performed by settling and decanting, filter or belt pressing, or centrifuging.

Pretreatment (stabilization, fixation, or encapsulation) of material may be required to bind free water and prevent leachate development from the excavated wastes once disposed of off site. Pretreatment processes are usually done during staging. Liquids generated during dewatering may also require treatment prior to shipment or discharge.

Loading may be direct (e.g., from the bucket excavator) but is more typically done with front-end loaders after stockpiling, classifying, and pretreating solids and sludges. Waste materials are typically disposed of in permitted treatment, storage and disposal facilities (TSDFs).

b. Applications.

Landfill disposal typically requires that no free liquid be present in the material and/or that the materials meet TCLP leaching criteria. Volatile organic compounds (VOCs) may be volatilized from the solids or sludges during excavation; consequently excavation, transport, and disposal off site are not usually appropriate for wastes high in hazardous volatiles such as BTEX (benzene, toluene, ethylbenzene, xeylene), ketones, or chlorinated solvents (e.g., methylene chloride) unless pretreated in some manner to minimize volatile loss to the environment. Semi-volatile organic materials and inorganic contaminants can also be released into the air as particulate matter.

3-3. Hazard Analysis.

Principal unique hazards associated with excavation, removal, and off-site disposal; methods for control; and control points are described below.

a. Physical Hazards.

(1) Equipment.
Description: During soil excavation, workers may be seriously injured or killed by heavy equipment such as front-end loaders and scrapers. This equipment may also generate excessive noise during operation.

Control: Controls for equipment hazards include

- Use heavy equipment with a backup alarm to alert workers.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Wear hearing protection when working around operating equipment.

CONTROL POINT: Construction, Operations, Maintenance

(2) Fire and Explosion or Utility Hazards.
Description: During excavation into soil contaminated with explosive, flammable, or combustible materials (e.g., carbon disulfide, hydrogen sulfide, methane, tetraethyl lead), under unusual or extraordinary conditions, the bucket of a backhoe or cutting blade of a crawler may spark from rocks, buried metal, or other objects and ignite a flammable vapor. During excavation activities, a backhoe or other earth-moving equipment may rupture an underground utility, such as electrical or gas lines, and cause a fire, explosion, or electrocution.

Control: Controls for fire and explosion hazards include

- Locate underground electrical utilities using electromagnetic surveys, inductance surveys, installation maps and drawings, locating services, interviews with utilities personnel, and hand excavation prior to machine excavating.
- Adhere to the excavation safety requirements of 29 CFR 1926.650-.652.
- Equip earth-moving equipment with a non-sparking bucket or blade.
- Wet or foam the active work area periodically with water or a foam fire suppressant to prevent vapor ignition. The addition of foam to control vapors may also create a slip and fall hazard. Do not allow workers where foam has been applied.
- Conduct area monitoring when airborne combustible chemical concentrations may exceed greater than 1/10 the Lower Explosive Limit (LEL).

CONTROL POINT: Design, Construction, Operations

(3) Excavation Wall Collapse or Flooding.
Description: Entry into an excavation may expose workers to confined-space atmospheric dangers and risk of excavated wall collapse. Flooding of an excavation may cause drowning or electrocution if electrical equipment is in use.

Control: Controls for wall collapse or flooding include
- Wear inflation vests, use water lockout procedures, and develop a plan to evacuate workers in basins or impoundments with the potential for rapid flooding.
- Slope the walls of all excavations greater than 5 feet away from the edge or properly shore in accordance with Occupational Safety and Health Administration (OSHA) guidance (29 CFR 1926.650-652).
- Do not allow workers to enter an unstable excavation.

When confined-space hazards are known or suspected, appropriate health and safety steps include
- Ventilate the area and entry using supplied air and confined-space techniques and follow procedures (29 CFR 1910.146) for eliminating the hazard.
- Implement a confined-space atmospheric testing program using an oxygen meter, combustible gas meter, and other specific hazardous gas meters as part of the confined-space entry program. A confined space is defined as any space with the potential to hold toxic, asphyxiant, or explosive concentrations of gas whether more dense (e.g., sump, basement, tank, or excavation) or less dense (e.g., low canopy or roofed tank) than air.
- Follow confined-space entry procedures (29 CFR 1910.146) for excavations greater than 4 feet. Regardless of the depth, a competent person must assess the excavation prior to each entry.

CONTROL POINT: Design, Construction, Operations

(4) Skin Puncture/Cut Hazards.
Description: Workers may also be exposed to skin puncture and cut hazards during the excavation and transport of sharp or abrasive objects contained within waste material.

Control: Controls for skin puncture/cut hazards include
- Use personal protective equipment (PPE), including boots and gloves made of puncture-resistant materials. Work boots should be equipped with steel-reinforced shanks to help prevent puncture when walking over waste materials.
- Handle materials with appropriate equipment, not hands or feet, to avoid injury.
- Remove materials posing a clear potential hazard (e.g., framing lumber with nails, broken glass) carefully to avoid later, inadvertent contact.

CONTROL POINT: Construction, Operations, Maintenance

(5) Steam Pressure Washing.
Description: Steam pressure washing of equipment may expose workers to thermal or burn hazards, eye hazards due to flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control: Controls for steam pressure washing include
- Use insulated gloves (e.g., silica fabric gloves).
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from decontamination operations into a tank or pit. Drain walking surfaces and keep free of standing liquids and mud.

CONTROL POINT: Construction, Operations

(6) Unstable Soil Conditions.
Description: Operating heavy equipment over unstable ground (ground that has been affected by pumping or involved in subsurface treatments) may cause the ground surface to subside or sink. The result may cause an injury to the operator of the equipment or to nearby workers.

Control: A control for unstable soil conditions includes
- Use a qualified engineer to access soil to ensure safe site conditions for equipment operation.

CONTROL POINT: Design

(7) Respirable Quartz Hazard.
Description: Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422, followed by analysis of the fines by X-ray diffraction to determine fine material quartz content.

Control: Controls for respirable quartz hazards include
- Wet the soil periodically with water or amended water to minimize worker exposure.
- Use respiratory protection, such as an air-purifying respirator equipped with a HEPA (N100, R100, P100) filter/cartridge.

CONTROL POINT: Construction, Operations

(8) UV Radiation.
Description: During site activities, workers may be exposed to direct and indirect sunlight and the corresponding ultraviolet (UV) radiation. Even short-

term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control: Controls for UV radiation include

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen.
- Shade the work and break areas if possible.
- Minimize exposure to heat stress by taking frequent breaks, drinking adequate fluids, and performing work during the early morning and late afternoon hours.

CONTROL POINT: Construction, Operations

(9) Utility Contact Hazards.
Description: Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control: Controls for utility contact hazards include

- Note the location of overhead power lines, either existing or proposed, in the pre-design phase.
- Keep all lifting equipment, such as cranes, forklifts, and drilling rigs at least 10 feet from the power line according to OSHA regulations 29 CFR 1926.550 and EM 385-1-1, Section 11.E.

CONTROL POINT: Design, Construction, Operations

(10) Traffic Hazards.
Description: During the implementation of field activities, equipment and workers may come in close proximity to traffic. Also, drilling rigs and other equipment may need to use public roads. The general public may be exposed to traffic hazards and the potential for accidents during loading and transporting soil.

Control: Controls for traffic hazards include

- Post warning signs where equipment crosses roads according to the criteria of the Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways.
- Develop a traffic management plan before remediation activities begin to help prevent accidents involving site trucks and automobiles. EM 385-1-1, Section 21.I.10 provides plan details.

CONTROL POINT: Design, Construction, Operations

(11) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical

surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

Contaminatio n Hazards.
Description: Workers involved with excavation activities may be exposed to VOCs and particulate matter contaminated with semi-volatile organic and/or inorganic contaminants. Inhalation hazards are particularly evident during warm and dry periods when there is a greater chance for airborne dusts to be generated. The addition of foam to control vapors and/or dust may create a slip hazard. Workers may also be dermally exposed to waste materials during excavation and transport of waste materials. Workers may inadvertently ingest contaminants/waste materials that collect on hands and clothing in the form of dust during excavation. Dust ingestion may also occur when workers take water/meal breaks, or after they have left the work area if established hygiene procedures (e.g., washing hands) are not followed.

Control: Controls for chemical contamination hazards include

- Use proper types of PPE as necessary. Examples of PPE include nitrile gloves for dermal exposure to gasoline, an air-purifying respirator equipped with approved HEPA filter (N100, R100, P100) for particulates, organic vapor (OV) cartridges for vapors, or combination filter/cartridges for dual protection, and chemically-resistant disposable coveralls.
- Use experienced workers, repeated health and safety awareness meetings, decontamination stations, and other standard procedures.
- Suppress dust and other emissions using water or foam suppressants if needed. Workers should not walk on areas where foam has been applied.
- Test soils for reactive, highly flammable, or corrosive materials. In extreme conditions (e.g., carbon disulfide CS_2) non-sparking tools and intrinsically safe equipment may be required if emissions are expected to be high.

CONTROL POINT: Construction, Operations

c. Radiological Hazards

Radioactive Material.
Description: Naturally occurring radioactive material (NORM) is found in all soils, groundwater, and surface water. At typical background levels, this radioactive material poses neither an internal nor an external hazard during excavation, removal, and/or off-site disposal activities. Elevated levels of naturally occurring radioactivity, however, have been found in materials such as sewage sludge, fossil fuels, fertilizers, and evaporation ponds. Excavation, removal, and/or off-site disposal of radioactive material at greater than background concentrations may pose an internal hazard if radioactive particles are inhaled or ingested. Certain devices containing radioactive material may also be present in the soils and/or rubbish to be excavated and handled (e.g., U.S. Army and U.S. Air Force gauges painted with radium-226, compasses, and radar devices). Intact radium gauges will not yield an unacceptable extremity dose. Broken gauges may present an internal hazard if radium paint chips are inhaled or ingested.

An external hazard may also exist depending upon the type and extent of contamination. Small particles of uranium metal and some uranium alloys are pyrophoric. They can ignite spontaneously in air as a function of surface to volume ratio. They burn rapidly at very high temperatures.

Control: Controls for radioactive materials include
- Consult a qualified health physicist whenever significant radioactive hazards above background are suspected.
- Review site history thoroughly for evidence of concentrated NORM or for the presence of devices containing radioactive material.
- Use time, distance, and shielding to control external hazards from ionizing radiation.
- Use PPE to prevent external contamination.
- Use HEPA respiratory protection (N100, R100, P100 filters) and engineering controls for internal hazards.
- Use decontamination procedures/facilities as necessary to reduce radiation exposure.
- Suppress dust and other emissions as described above for chemical hazards.

CONTROL POINT: Design, Construction, Operations

d. Biological Hazards.

(1) Biological Contaminants.
Description: Microorganisms in the groundwater and soil may cause exposure hazards at sites containing medical wastes or sewage sludge. Workers may be exposed to inhalation/ingestion and/or dermal contact with pathogens such as *Coccidioides sp., Histoplasma sp.,* and *Mycobacterium sp.*

Control: Controls for biological contaminants include

- Test the microorganisms in the groundwater and soil and determine the appropriate PPE to prevent exposure. The appropriate PPE may include an air-purifying respirator equipped with HEPA (N100, R100, P100) filters. Most rubber gloves (e.g., nitrile or PVC) provide protection against microorganisms; however, the type of glove used must also be compatible with contaminants at the site. The use of latex gloves may aggravate or cause allergic reactions in some people.
- Use dust suppression with water or amended water sprays.
- Enforce (strictly) eating, drinking, and smoking restrictions prior to washing/decontamination. Decontamination with water and or disinfectant soaps may be used to control exposure.
- Wear chemically-resistant protective overalls to prevent clothes from becoming grossly contaminated with wastes, soils, and/or contaminated water. If contaminated clothing is to be laundered, use a commercial laundry familiar with cleaning procedures for industrial clothing. These procedures include employee hazard warnings and cleaning solution disposal requirements.

CONTROL POINT: Design, Construction, Operations

(2) Pests.
Description: Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus.

Control: Controls for pests include

- Perform periodic inspections of the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies for removal.
- Use tick and insect repellents for exposure control. Workers should check their skin and clothing for ticks periodically throughout the work day.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 4
Solidification/Stabilization (Ex Situ/In Situ)

4-1. General.

The process of solidification/stabilization, ex-situ methods, in-situ methods, binding agents, and applications are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

4-2. Technology Description.

a. Process of Solidification/Stabilization.

Solidification/stabilization is the use of various chemical additives (Portland cement, kiln dust, and fly ash) to chemically bind and immobilize contaminants or to micro-encapsulate them in a matrix that physically prevents mobility. Solidification generally refers to a physical process where a semi-solid material or sludge is treated to render it more solid. Stabilization typically refers to a chemical process that actually binds the matrix of the contaminant such that its constituents are immobilized. Functionally, these processes either chemically bind or physically trap the contaminants. The terms *solidification* and *stabilization* refer to the formation of chemically as well as physically stable matrices. Solidification and stabilization can be done in situ or ex situ.

b. Ex-situ Methods.

Field processes involve excavation and staging of the solids, screening to remove materials too large in diameter to be effectively treated (often 2 inches in diameter or greater), blending the binding agents and water with solids (typically in a pug mill), and stockpiling treated solids for testing prior to shipment off site or placement back in the excavation. Solidification/stabilization is most effective on metals and inorganic contaminants, and less effective with increasing concentrations of organic contaminants. Figure 4-1 illustrates the in-situ and ex-situ solidification/stabilization processes. Solidification/stabilization can result in monolithic-formed blocks or chunks, or in a soil-like matrix.

A significant consideration in applying the ex-situ technology is the "swell factor" in the solid volume created by the binding agent; this factor is dependent on the amount of reagents which must be added and can approach 50 percent in some cases. Not all of the treated material may fit in the same excavation from which it was removed without altering the natural grade.

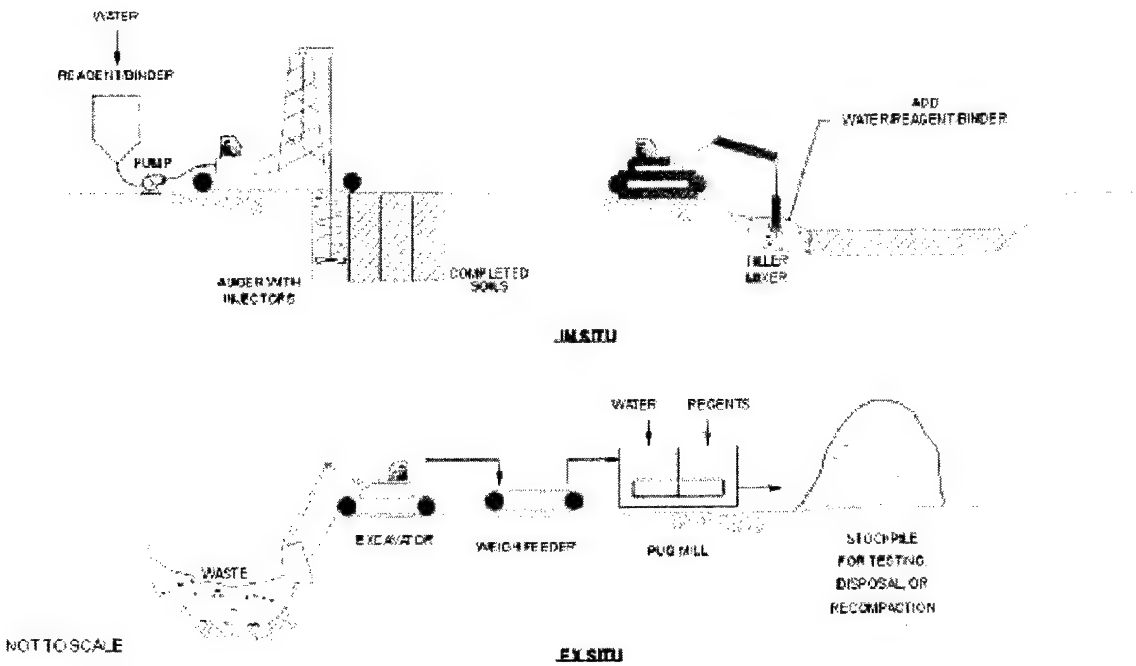


FIGURE 4-1. SOLIDIFICATION/STABILIZATION (IN SITU/EX SITU)

c. In-situ Methods.

In-situ solidification/stabilization involves the injection and/or mixing of stabilizing agents into subsurface soils to immobilize the soil matrix and contaminants to prevent leaching into infiltrating precipitation or groundwater. Typically, in-situ stabilization involves the addition of binding agents to an area of sludge or soils, addition of water if necessary, and then repeated in-place mixing with the bucket of a back or track hoe to thoroughly mix and stabilize the sludges or soils in place. A growing method of in-situ solidification/stabilization is the use of very large flighted rotary augers 6-8 or more feet in diameter, capable of injecting slurry chemicals and water through the auger flights. The auger bores and mixes a large diameter "plug" of the contaminated material. During augering, stabilization chemicals and water (if needed) are injected into the soils. When thoroughly mixed, the auger is removed and the setting slurry is left in place. The auger is advanced to overlap the last "plug" slightly and the process is repeated until the contaminated area is completed. The solidification/stabilization additives are the same as with other in-situ or ex-situ techniques, but the process provides better *in-situ* mixing and distribution of additives.

d. Binding Agents.

Typical binding/stabilizing agents (in situ or ex situ) include Portland cement, pozzolanic binders, and various kiln dusts. Most of these materials are highly alkaline, and form a solidified matrix when mixed with the contaminated material.

Ex-situ solidification/stabilization uses the same kinds of binding/stabilizing agents as those used in-situ, but solids are excavated and treated in mixing equipment, such as pug mills or cement mixers outside the original waste locations. The material handling requirements of this approach are greater than for in-situ methods, but the degree of mixing and blending control is significantly higher than for in-situ processing. This generally yields higher confidence that the contaminants have been effectively immobilized and may require less reagent per unit volume of solids treated.

e. Applications.

The solidification/stabilization process has been successfully demonstrated and used for inorganic contaminants, primarily metals, and radionuclides in the presence of low levels of organic materials. The process is not considered routinely applicable for situations where organic content of the wastes/soil, as measured by total petroleum hydrocarbons (TPH) is greater than 5,000-10,000 mg/kg because the organic material has leached out of the cement matrix over several years in some cases. The addition of activated carbon and other adsorbents can enhance the levels of organics practically treatable with this technology.

4-3. Hazard Analysis.

Principal unique hazards associated with solidification/stabilization (ex-situ/in-situ), methods for control, and control points are described below:

a. Physical Hazards.

(1) Equipment Hazards.
Description: During soil excavation, workers may be seriously injured or killed by heavy equipment such as front-end loaders, tillers, scrapers, and other equipment.

Control: Controls for equipment hazards include

- Use heavy equipment with a backup alarm to alert workers.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.

CONTROL POINT: Construction, Operations

(2) Auger/Caisson Hazards.
Description: Installation of auger/caisson systems poses mechanical hazards due to the use of large rotating augers. During the in-situ stabilization process, heavy equipment and materials, such as augers and caissons are periodically raised overhead and placed into position. Workers may be exposed to swinging equipment or crushing hazards if the equipment falls.

Control: Controls for auger/caisson hazards include

- Establish a work zone and allow only those personnel necessary for the task in the zone.
- Inspect lifting equipment regularly and operate safely.
- Raise equipment only as high as needed and minimize the movement of raised equipment.
- Avoid contact with auger edges, cables, and pipe and wear appropriate personal protective equipment (PPE) including hard hats, steel-toe shoes, instep guards, and appropriate clothing.

CONTROL POINT: Construction, Operations

(3) Rotating Equipment Hazards.
Description: Rotating augers or backhoes pose hazards to workers as loose clothing may become entangled with the revolving augers.

Control: Controls for rotating equipment include
- Secure all loose clothing.
- Stay clear of rotating and moving equipment.

CONTROL POINT: Construction, Operations

(4) Utility Contact Hazards.
Description: Fire and explosion hazards may exist when using augers or other drilling methods if the auger contacts and/or ruptures underground utilities such as electric or gas lines or underground tanks. Also, underground obstructions, such as sewers and foundations, may cause drilling equipment to abruptly stop, resulting in unsafe drilling conditions. Electrocution hazards may also exist if large stabilization augers come in contact with overhead electrical wiring during placement or operation.

Control: Controls for utility contact hazards include
- Identify the location of all below- and above-ground utilities prior to drilling by contacting local utilities and public works personnel. When there is any doubt or uncertainty, carefully excavate with a backhoe, probe with a metal rod, or hand excavate to determine the exact location of utilities. Once utilities are located, careful excavation by backhoe may be allowed.
- Post an observer to the side to direct the raising of a drill mast.

- Do not move the drilling rig with the mast raised.

CONTROL POINT: Design, Construction, Operations

(5) Unguarded Moving Mechanisms.
Description: Pug mills and similar equipment used to mix soils may be equipped with unguarded drive shafts, sprockets, chains, pulleys, or other revolving/rotating mechanisms. Exposure to the unguarded equipment may result in workers becoming entangled.

Control: Controls for unguarded moving mechanism include

- Guard all moving mechanisms to prevent accidental contact.
- Operate equipment only when guards are in place
- Wear appropriate PPE and clothing. No loose clothing should be worn, shirt tails should be tucked in, and long sleeves should be buttoned.
- Restrain long hair under hard hats.

CONTROL POINT: Design, Construction, Operations

(6) Explosive Gases.
Description: Solidification/stabilization can sometimes cause off gassing of dangerous substances. As an example, when quantities of magnesium are present, solidification/stabilization with cement will cause off gassing of hydrogen from a water-magnesium reaction and present a fire/explosion hazard. This can be a problem with stabilization in drums and other containers.

Control: Controls for explosive gases include

- Evaluate during design what off gases, if any, to expect.
- Ventilate the work areas where stabilization is taking place.
- Monitor as necessary for explosive gases.

CONTROL POINT: Design, Construction, Operations

(7) Steam Pressure Washing.
Description: Steam pressure washing of equipment may expose workers to thermal or burn hazards, eye hazards due to flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control: Controls for steam pressure washing include

- Use insulated gloves (e.g., silica fabric gloves).
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations

(8) Respirable Quartz Hazard.

Description: Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g. to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz potential, sample and analyze site soils for fines content by ASTM D422, followed by analysis of the fines by X-ray diffraction to determine fine material quartz content.

Control: Controls for respirable quartz include

- Wet the soil periodically with water or amended water to minimize worker exposure.
- Use respiratory protection, such as an air-purifying respirator equipped with a HEPA (N100, R100, P100) filter.

CONTROL POINT: Construction, Operations

(9) UV Radiation.

Description: During site activities, workers may be exposed to direct and indirect sunlight and the corresponding UV radiation. Even short-term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control: Controls for UV radiation include

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen.
- Shade work and break areas, if possible.
- Minimize exposure to heat stress conditions by taking frequent breaks, drinking adequate fluids, and performing work during the early morning and late afternoon hours.

CONTROL POINT: Construction, Operations

(10) Electrocution Hazards.

Description: Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control: Controls for electrocution hazards include

- Verify the location of overhead power lines, either existing or proposed in the pre-design phase.
- Keep all lifting equipment, such as cranes, forklifts, and drilling rigs at least 10 feet from the power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.E.

CONTROL POINT: Design, Construction, Operations

(11) Heavy Equipment Hazards.
Description: The heavy equipment (small and large) used for site operations may roll over on steep slopes or unstable ground, crushing the operator.

Control: Controls for heavy equipment hazards include
- Design the angle of the slope to minimize the potential for roll-over.
- Maintain safe operating conditions for equipment during construction (construction contractor).
- Use heavy equipment with roll-over protective devices (ROPS) and do not operate on steep slopes or unstable ground.

CONTROL POINT: Design, Construction, Operations

(12) Traffic Hazards.
Description: During the implementation of field activities, equipment and workers may come in close proximity to traffic. Also, drilling rigs and other equipment may need to cross or use public roads. The general public may be exposed to traffic hazards and the potential for accidents during loading and transporting soil.

Control: Controls for traffic hazards include
- Post warning signs where equipment crosses roads according to the criteria of the Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways.
- Develop a traffic management plan before remediation activities begin to help prevent accidents involving site trucks and automobiles. EM 385-1-1, Section 21.I.10 provides plan details.

CONTROL POINT: Design, Construction, Operations

(13) Muscle Injuries.
Description: Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control: Controls for muscle strain include
- Use mechanical lifting equipment to lift heavy loads.
- Use proper lifting techniques including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385-1-1, Section 14.A.

CONTROL POINT: Design, Construction, Operations, Maintenance

(14) Noise Hazards.
Description: The operation of both in-situ and ex-situ solidification/stabilization systems may present a noise hazard to workers.

Control: A control for noise hazards includes

- Wear hearing protection in accordance with 29 CFR 1910.95 and 29 CFR 1926.521 requirements as necessary around operating equipment.

CONTROL POINT: Construction, Operation

(15) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards

(1) Contamination Hazards.
Description: During excavation and mixing operations (in-situ or ex-situ), workers may be exposed to inhalation/ingestion/dermal hazards from airborne contaminated dusts, VOCs, and waste materials. These materials may include: Portland cement, quicklime, hydrated lime, kiln dust, fly ash, sodium silicate, and gypsum. Also, the addition of cement may result in chemical release to the air due to chemical reactions with waste materials. Eye exposure to airborne dusts and chemicals may occur, resulting in irritation, scratching, and scarring of eyes. High-pressure injection of stabilizing compounds can spray or splatter chemical agents that may also cause eye damage.

Control: Controls for contamination hazards include

- Reduce airborne contaminants by applying water periodically to the active excavation and mixing areas.
- Use injection equipment with pressure-trip interlocks to prevent operation at excessive pressures.
- Select the proper types of PPE: an air-purifying respirator with approved HEPA (N100, R100, P100) filters for particulates, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Wear eye protection.
- Offer frequent health and safety awareness meetings.

- Use experienced workers and decontamination stations.

CONTROL POINT: Design, Construction, Operations

(2) Chemical Exposure.
Description: During the excavation process, accidental rupturing of underground utilities, such as sewers and pipelines containing gases and liquids, may result in worker exposure to chemicals.

Control: A control for chemical exposure includes
- Identify underground utility location by contacting local utilities/public works personnel.
- Locate the below-ground utilities and probe with a metal rod prior to excavating to prevent underground rupture.

CONTROL POINT: Construction, Operations

(3) VOCs Exposure.
Description: Enhanced off gassing of VOCs may occur as a result of the heat generated during the stabilization process. Also, ammonium compounds may release ammonia when mixed with cement. Workers may be exposed to VOCs via inhalation or dermal exposure routes.

Control: Controls for VOCs exposure include
- Reduce airborne VOCs by the periodic application of water or emission-suppressing foams to the active excavation and mixing areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas to which foam has been applied.
- Minimize the amount of soil agitation during mixing operations.
- Erect wind screens and portable surface covers.
- Use the proper types of PPE: an air-purifying respirator equipped with approved HEPA (N100, R100, P100) filters for particulates, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Offer frequent health and safety awareness meetings, use experienced workers, decontamination stations, and other standard procedures.

CONTROL POINT: Design, Operations

c. Radiological Hazards

Contaminant Hazards.
Description: Contaminants in excavated or in-situ soils, sludge, and associated water may pose a rare radiation hazard. Naturally occurring radioactive material (NORM) may be present in the soils, sludge, and groundwater. Some radioactive materials are pyrophoric. Radioactive materials of uranium or thorium may spontaneously ignite and pose a fire hazard and an airborne radioactivity hazard. Buried radioactive materials may present an external

hazard. All radioactive materials may present an internal hazard through inhalation or ingestion.

Control: Controls for contaminant hazards include

- Test soil, sludge, and water to identify and eliminate exposure potential during excavation, classification, and disposal. The presence of radiation or particulate radioactive materials, and their nature and extent, should be determined by a qualified health physicist.
- Use appropriate engineering, PPE, and other controls to prevent exposure.
- Make decontamination facilities available to help minimize exposure.
- Suppress dust and other emissions using periodic applications of water or amended water.

CONTROL POINT: Design, Operations

d. Biological Hazards

(1) Biological Contaminants.
Description: At those sites involving medical wastes or sewage sludge, microorganisms in the soil may cause exposure hazards during soil mixing and waste stabilization activities. Workers may be exposed to inhalation/ingestion/dermal contact with pathogens such as *Coccidioides sp., Histoplasma sp.,* and *Mycobacterium sp.*

Control: Controls for biological contaminants include

- Test microorganisms in the soil and determine the appropriate PPE to help control exposure.
- Reduce the generation of airborne contaminants, including microbes and particles (dust), with the periodic application of water or emission-suppressing foams to the active excavation and mixing areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas where foam has been applied.
- Use the proper types of PPE: an air-purifying respirator equipped with approved HEPA (N100, R100, P100) filters for particulates, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Offer frequent health and safety awareness meetings, use experienced workers, decontamination stations, and other standard procedures.

CONTROL POINT: Design, Construction, Operations

(2) Pests.
Description: Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus.

Control: Controls for pests include

- Perform periodic inspections of the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents for exposure control. Workers should check their skin and clothing for ticks periodically throughout the work day.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 5
Slurry Walls

5-1. General.

The design and function of slurry walls and specific uses of cement/bentonite walls are discussed in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

5-2. Technology Description.

a. Design and Function of Slurry Walls.

A slurry wall is an in-ground physical containment device designed to isolate contaminant source zones and groundwater plumes from the surrounding environment. Contaminated soil, wastes, and/or groundwater can be physically isolated within surrounding low-permeability barriers by constructing a vertical trench excavated down to and keyed into a deeper confining layer, such as a low-permeability clay or shale and filling the trench with a slurry. Slurry walls usually consist of a soil, bentonite, and/or cement mixture. The slurry mix hydraulically shores the trench to prevent collapse during installation and forms a permeation barrier to prevent the escape of contaminants from the contained area. As the excavation continues, additional slurry is added, and the process continues until the depth and length needed is completed. A schematic diagram of a slurry wall configuration is presented in Figure 5-1.

Slurry walls are commonly used subsurface barriers because they are a relatively inexpensive means of reducing groundwater flow in unconsolidated earth material and are also useful for sites where present technologies can not effectively or economically treat contaminant sources. Cement and bentonite construction of a wall can adsorb and retard the escape of heavy metals and larger organic molecules but can not completely stop water movement. Consequently, slurry walls are either "stop-gap" measures or are typically accompanied (as illustrated in Figure 5-1) by pump-and-treat systems. Often the enclosed area is capped or covered to prevent additional infiltration of water behind the wall.

Slurry walls are also used to direct or funnel the flow of groundwater to pump-and-treat well arrays or in-situ treatment areas, such as a reactive wall or biosparging array. Soil/bentonite walls have been used for decades for groundwater control in conjunction with large dam projects. However, the ability of these walls to withstand long-term permeation by many contaminants is unknown. Evidence indicates that

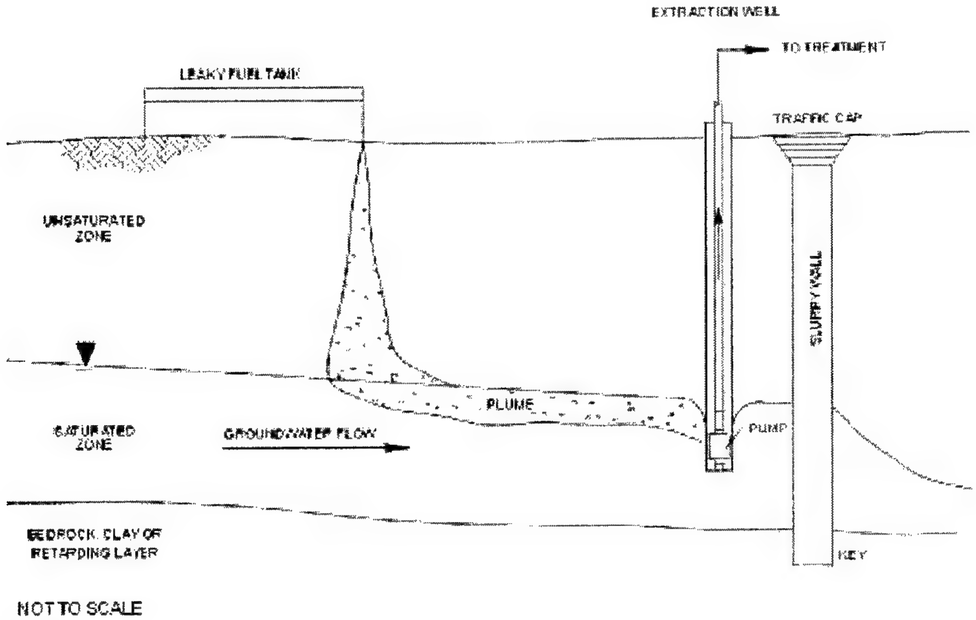


FIGURE 5-1. SLURRY WALLS

soil/bentonite backfills are not able to withstand attack by strong acids and bases, strong salt solutions, and some organic chemicals.

b. Cement/Bentonite Walls.

Cement/bentonite walls are more expensive than soil/bentonite walls and are generally used where: (1) there is no room to mix and place soil-bentonite backfills; (2) increased mechanical strength is required; or (3) extreme topography conditions (slopes) make it impractical to grade a site level. Cement/bentonite slurry walls are limited in their use by their higher permeability and their narrow range of chemical compatibilities (more susceptible to attack by sulfates, strong acids or acid bases, and other highly ionic substances).

5-3 Hazard Analysis.

Principal unique hazards associated with the slurry walls, methods for control, and control points are described below.

a. Physical Hazards.

(1) Equipment Hazards.

Description: During soil excavation, workers may be seriously injured or killed by heavy equipment such as front-end loaders and backhoes. This equipment may also cause a noise hazard to workers.

Control: Controls for equipment hazards include

- Use heavy equipment with a backup alarm to alert workers.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Wear hearing protection around operating equipment.

CONTROL POINT: Construction

(2) Utility or Underground Structure Hazards.
Description: Fire, electrocution, or explosion hazards may exist during installation of the slurry wall if a backhoe ruptures an underground utility, such as sewers, pipelines, or electrical or gas lines. Abrupt equipment stoppages due to contact with underground structures, such as foundations, may cause a dangerous condition leading to equipment-related accidents.

Control: Controls for utility and underground structure hazards include

- Identify the location of all below- and above-ground utilities prior to excavation by contacting local utilities and public works personnel. When there is any doubt or uncertainty, perform a utility survey, probe with a metal rod, or hand excavate prior to excavation to determine the exact location of utilities. Once utilities are located, careful excavation by backhoe may be allowed.
- Post an observer to the side to observe and supervise when raising a drill mast or other equipment.

CONTROL POINT: Design, Construction

(3) Trench Hazards.
Description: Open excavations may pose fall hazards to workers while performing activities near the trench. The trench wall may collapse or the worker may fall into the trench while performing trench depth measurements or sample collection.

Control: Controls for trench hazards include

- Inspect the excavation each day to ensure the stability of the walls.
- Limit worker activities near the excavation and only approach wearing fall protection, such as a safety harness and/or attached lanyard.
- Equip all personnel crossings with handrails.

CONTROL POINT: Construction, Operations

(4) Steam Pressure Washing.

Description: Steam pressure washing of equipment may expose workers to thermal or burn hazards, eye hazards due to flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control: Controls for steam pressure washing include
- Use insulated gloves (e.g., silica fabric gloves).
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations

(5) UV Radiation.
Description: During site activities, workers may be exposed to direct and indirect sunlight and corresponding UV radiation. Even short-term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control: Controls for UV radiation include
- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen.
- Shade work and break areas if possible.
- Minimize exposure to heat stress by taking frequent breaks, drinking adequate fluids, and performing work during the early morning and late afternoon hours.

CONTROL POINT: Construction, Operations

(6) Electrocution Hazards.
Description: Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control: Controls for electrocution hazards include
- Verify the location of overhead power lines, either existing or proposed, in the pre-design phase.
- Keep all lifting equipment, such as cranes, forklifts, and drilling rigs at least 10 feet from the power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.E.

CONTROL POINT: Design, Construction, Operations

(7) Heavy Equipment Hazards.
Description: The heavy equipment (small and large) used for site operations may roll over on steep slopes or unstable ground, seriously injuring the

operator. Trucks loaded with backfill can back up too far and become stuck in the trench.

Control: Controls for heavy equipment hazards include

- Design the angle of the slope to minimize the potential for roll-over.
- Maintain safe operating conditions for equipment during construction (construction contractor).
- Use heavy equipment with roll-over protective devices (ROPS) and do not operate on steep slopes or unstable ground.

CONTROL POINT: Design, Construction, Operations

(8) Traffic Hazards.
Description: During the implementation of field activities, equipment and workers may come in close proximity to traffic. Also, drilling rigs and other equipment may need to cross or use public roads. The general public may be exposed to traffic hazards and the potential for accidents during loading and transporting soil.

Control: Controls for traffic hazards include

- Post warning signs according to the criteria of the Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways.
- Develop a traffic management plan before remediation activities begin to help prevent accidents involving site trucks and automobiles. EM 385-1-1, Section 21.I.10 provides plan details.

CONTROL POINT: Design, Construction, Operations

(9) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards

Slurry/Contamination Hazards.
Description: During excavation/mixing/installation operations, workers may be exposed to inhalation/ingestion/dermal hazards from caustic irritants such as Portland cement, airborne dusts, volatile organic compounds (VOCs), metals, or free silica from soil/bentonite mixtures and waste materials. Eye exposure may occur resulting in scratching and scarring of eyes.

Control: Controls for contamination hazards include

- Reduce airborne dusts by periodically applying water, amended water, or emission-suppressing foams to the active excavation and mixing areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas to which foam has been applied.
- Minimize the amount of soil agitation during mixing operations.
- Erect wind screens and portable surface covers.
- Use the proper types of PPE: an air-purifying respirator equipped with approved HEPA (N100, R100, P100) filters for particulates, OV cartridges for vapors, or combination filter/cartridges for dual protection, and eye protection.
- Use experienced workers, frequent health and safety meetings, decontamination stations, and other standard procedures.

CONTROL POINT: Design, Construction, Operations

c. Radiological Hazards.

Radioactive Material.
Description: Radiological materials may have been buried or naturally occurring radioactive material (NORM) may be present in the excavated soils, sludge, and groundwater. Some radioactive materials may present an external hazard. All radioactive materials may present an internal exposure hazard through inhalation or ingestion. *Note that this may be a rare hazard to encounter using this remediation technology.*

Control: Controls for radioactive materials include

- Test excavated soil, sludge, or groundwater to determine if radioactive materials are present.
- Consult a qualified health physicist if any radioactive material above background levels is found. Consultation should result in determination of exposure potential, any necessary engineered controls, or PPE required.

CONTROL POINT: Design, Construction, Operations

d. Biological Hazards.

(1) Biological Contaminants.

Description: At those sites involving medical wastes or sewage sludge, microorganisms in the soil may cause exposure hazards during the soil mixing and waste stabilization activities. Workers may be exposed to inhalation/ingestion/dermal contact with pathogens, such as *Coccidioides sp., Histoplasma sp.,* and *Mycobacterium sp.* if contaminated dusts become airborne.

Control: Controls for biological contaminants include

- Reduce generation of airborne microbe-contaminated dust with the periodic application of water, amended water, or emission-suppressing foams to the active excavation and mixing areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas where foam has been applied.
- Minimize the amount of soil agitation during mixing operations.
- Erect wind screens and use portable surface covers.
- Use proper types of PPE: an air-purifying respirator with HEPA (N100, R100, P100) filter/cartridge.
- Use experienced workers, repeated health and safety meetings, decontamination stations, and other standard procedures.

CONTROL POINT: Design, Operations

(2) Pests.

Description: Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents, during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus.

Control: Controls for pests include

- Perform periodic inspections of the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents for exposure control. Workers should check their skin and clothing for ticks periodically throughout the workday.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 6
Soil Washing/Solvent Extraction

6-1. General.

The methods of soil washing and solvent extraction, their applications, and resulting waste streams are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

6-2. Technology Description.

a. Soil Washing.

(1) Process.
Soil washing typically uses water as the solvent (sometimes with wash-improving additives) to extract, desorb, and dissolve contaminants, particularly hydrophilic contaminants. It is also used to sort and separate the contaminated solids by size. Soil washing removes contaminants from soils by dissolving or suspending them in an aqueous wash solution or by concentrating them into a smaller volume of soils, typically the "fines," since this fraction has the highest specific surface area (surface area/volume or mass).

In the soil washing process (Figure 6-1), contaminated soil is screened and homogenized prior to being fed into the washing apparatus. Extraction agents (e.g., surfactants or pH modifiers such as hydrochloric acid) and makeup water are added to the soil. After sufficient mixing, remediated soils are separated from the water. Concentration of contaminants into a smaller volume of soil begins with the use of a "grizzly" to separate out large rocks and continues with various screening and controlled rate-settling processes. Oversized rejects are discarded and the remaining solids washed to separate fine (small) clay and silt particles from the coarser sand and gravel particles.

The success of this technology is based on the principle that most organic and inorganic contaminants preferentially bind, either chemically or physically to clay, silt, and organic soil particles. The smallest particles have a higher specific surface area, thus increasing their sorbed concentrations relative to volume or weight. The silt and clay are attached to sand and gravel by physical processes such as compaction and adhesion. For heavy metal compounds (such as lead or radium oxides), gravity separation can separate low- and high-specific gravity particles. Adherent contaminant films can be removed from coarser particles by attrition scrubbing. At the end of the process, the remediated solids can be

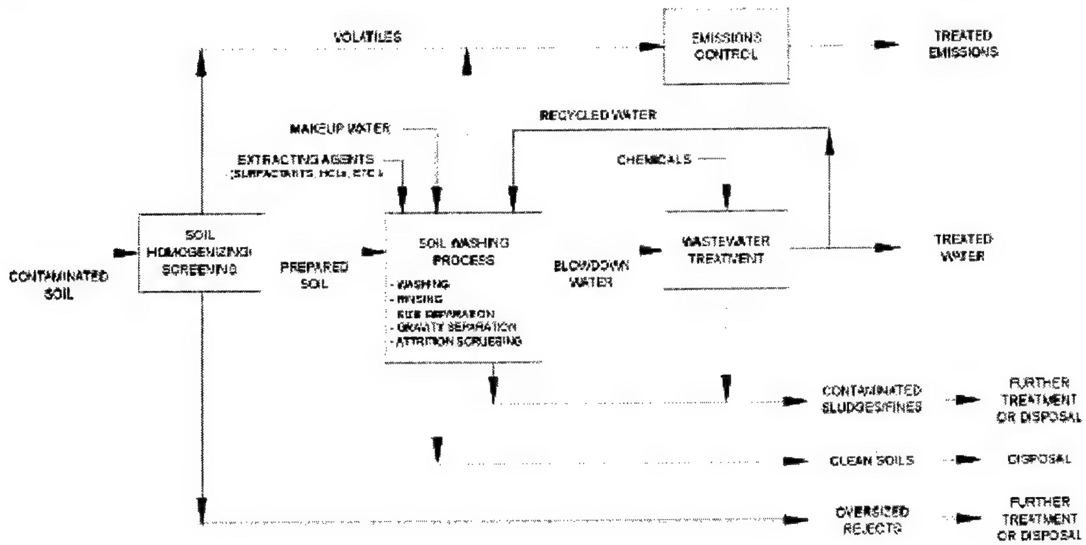


FIGURE 6-1. TYPICAL PROCESS FOR SOIL WASHING

returned to the site or disposed of off site. If the soil does not meet the agreed remediation criteria after washing, the process can be followed by additional treatment of the solids.

(2) Applications.
Soil washing has been applied to the remediation of semi-volatile compounds, fuels, and inorganics such as heavy metals and radionuclides. Under certain circumstances, the technology can be applied to volatile compounds and pesticides. Removal of fine soil particles (e.g., silts and clays) from the washing fluid may require the addition of polymeric materials such as flocculents.

(3) Resulting Waste Streams.
This process can produce up to five streams that may require additional handling or treatment:

- Volatile emissions from soil homogenization/screening (require additional treatment).
- Oversized rejects from soil preparation (require additional handling).
- Wastewater (requires additional treatment).
- Contaminated sludges/fines (require additional treatment).
- Solids (may require additional treatment).

The washwater is treated in a wastewater treatment plant and, whenever possible, treated water is recycled back into the washing apparatus.

b. Solvent Extraction.

(1) Process.
Solvent extraction uses a chemical solvent (usually organic) to extract, desorb, and dissolve contaminants. As illustrated in Figure 6-2, contaminated soil, sludge, or sediments are excavated, sized, and screened prior to the extraction process. The homogenized solids are mixed with solvents such as pentane, methyl ethyl ketone, or water-based solvents that extract much of the contaminants. The treated soil matrix is separated from the contaminated solvent and returned to the site after having met remediation cleanup criteria, including solvent concentrations. If the soil does not meet the agreed criteria, solvent extraction can be combined with other technologies to complete treatment. In the ideal version of the process, the contaminants are removed from the solvent and clean solvent recycled to the extractor.

The solvent should be selected based on the materials to be extracted and other practical characteristics (e.g., ease of recovery and reuse). The toxicity of the solvent is an important consideration if traces of solvent remain in the treated soils. Most solvent extraction processes use hydrophobic solvents such as pentane since most of the contaminants needing to be specifically extracted are hydrophobic. Hydrophilic contaminants may not be effectively removed by the usual organic solvent extractant, and the presence of detergents and emulsifiers can reduce the effectiveness of the technology. For hydrophilic contaminants, water or amended water-based solvents should be used as the solvent. The organic solvent technology is generally not used for extracting inorganics (e.g., acids, bases, salts, or heavy metals), and inorganics usually do not have a detrimental effect on the extraction process.

(2) Applications.
Solvent extraction has proven effective in treating sediments, sludges, and soils containing high concentrations of primarily organic contaminants such as polychlorinated biphenyls (PCBs), VOCs, halogenated solvents, and petroleum hydrocarbon wastes. Organically bound metals (e.g., alkyl lead or tin compounds) can be extracted along with the target organic contaminants, which may result in restricted handling of the residuals.

(3) Resulting Waste Streams.
The process can produce up to five streams that may require additional treatment or special handling:

- Emissions from waste preparation and solvent handling (requires additional treatment).
- Oversized rejects from waste preparation (requires additional treatment and/or handling).
- Water from moisture content of solids (requires additional handling and possible treatment).
- Concentrated contaminants (requires additional treatment).
- Solids (may require additional treatment).

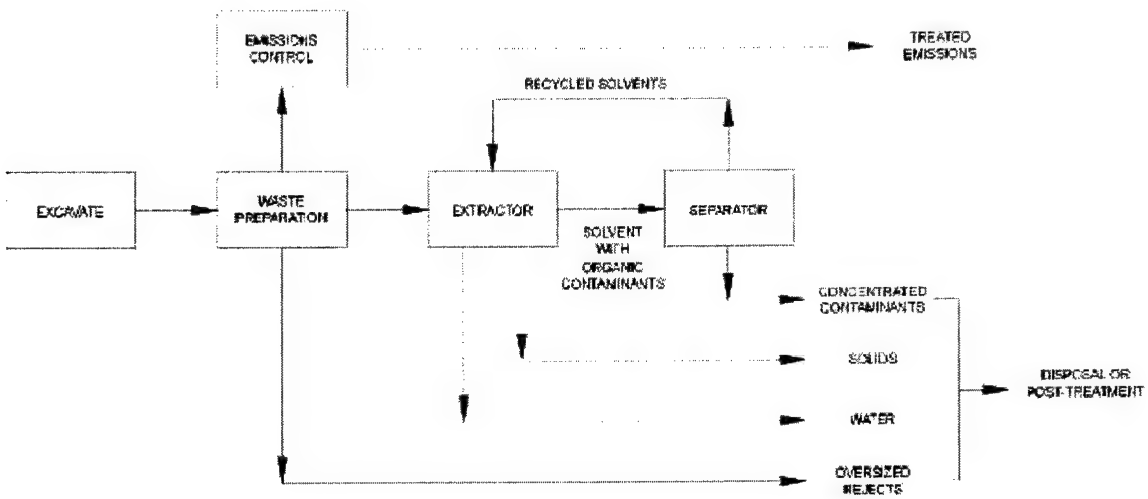


FIGURE 6-2. TYPICAL PROCESS FLOW FOR SOLVENT EXTRACTION

6-3. Hazard Analysis.

Principal unique hazards associated with soil washing/solvent extraction, methods for control and control points are described below.

a. Physical Hazards

(1) Equipment Hazards.
Description: During soil excavation, workers may be seriously injured or killed by heavy equipment such as front-end loaders and scrapers. This equipment may also cause a noise hazard.

Control: Controls for equipment hazards include
- Use heavy equipment with a backup alarm to alert workers.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Wear hearing protection around operating equipment.

CONTROL POINT: Construction, Operations

(2) Fire and Explosion Hazards.
Description: During excavation into soils saturated with flammable or combustible materials, fire or explosion hazards may exist. Under unusual or extraordinary conditions, the bucket of a backhoe or the blade of a crawler may cause a spark during contact with rocks, buried metal, or other objects and ignite a flammable vapor that may be created.

Control: Controls for fire and explosion hazards include
- Equip the backhoe with a non-sparking blade.
- Wet the active work area with water periodically.

CONTROL POINT: Design, Operations

(3) Unguarded Moving Equipment.
Description: The movement of soil from the excavation area to the treatment unit by use of a conveyor may constitute pinch-point hazards from unguarded rollers. Workers' clothing may become entangled with the rollers, causing injury or death.

Control: A control for minimizing exposure to moving equipment includes
- Use guards for conveyor belts, rollers, and associated equipment to prevent accidental contact.
- Train workers in identifying potential pinch points.
- Discourage the wearing of loose-fitting clothing.

CONTROL POINT: Design

(4) Fire and Explosion Hazards (Crushing Soils).
Description: Fire and explosion hazards may exist as soils containing flammable materials are crushed and sized or screened for treatment. As aggregate soils are crushed, sufficient heat may be generated to ignite vapors that have volatilized from the soil. Noise and vibration may also be present during equipment operation. Workers may also be exposed to flying projectiles as a result of the crushing/grinding operation.

Control: Controls for fire and explosion hazards during soil crushing include
- Reduce the potential for a fire or explosion with periodic application of water.
- Install equipment on vibration dampening bushings to reduce vibration and noise.
- Use baffles or sound deflecting/absorbing walls between the source and the operator to control noise and use hearing protection.
- Wear safety glasses with side shields to help prevent eye injuries from projectiles during operation of soil sizing and screening equipment.

CONTROL POINT: Construction, Operations

(5) Fire and Explosion Hazards (Distillation).
Description: Fire and explosion hazards may exist during distillation of solvents used in the extraction process. Over-pressurization may result in rupture of the vessel. The resulting release of flammable solvent may pose a fire or explosion hazard.

Control: Controls to prevent over-pressurization of distillation and solvent delivery systems include
- Use pressure relief valves and hazard warning alarms.

CONTROL POINT: Design

(6) Steam Pressure Washing.
Description: Steam pressure washing of equipment may expose workers to thermal or burn hazards, eye hazards due to flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control: Controls for steam pressure washing include
- Use insulated gloves (e.g., silica fabric gloves).
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(7) Respirable Quartz Hazard.
Description: Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422, followed by analysis of the fines by X-ray diffraction to determine fine material quartz content.

Control: Controls for respirable quartz include
- Wet the soil periodically with water or amended water to minimize worker exposure.
- Use respiratory protection, such as an air-purifying respirator equipped with a HEPA (N100, R100, P100) filter.

CONTROL POINT: Design, Construction, Operations

(8) UV Radiation.
Description: During site activities, workers may be exposed to direct and indirect sunlight and corresponding UV radiation. Even short-term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions may

also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control: Controls for UV radiation include

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen.
- Shade work and break areas if possible.
- Minimize exposure to heat stress by taking frequent breaks, drinking adequate fluids, and performing work during the early morning and late afternoon hours.

CONTROL POINT: Construction, Operations

(9) Confined-Space Hazards.
Description: Workers may be exposed to confined-space hazards during entry into mixing/reaction vessels for maintenance. Confined space may expose workers to toxic atmospheric hazards or to hazards associated with oxygen deprivation.

Control: Controls for confined-space hazards include

- Require testing of the atmosphere prior to entry into tanks, vessels, or other confined spaces.
- Ventilate the space and entry using supplied air and confined space techniques for eliminating the hazards (see 29 CFR 1910.146).
- Design air-handling systems to minimize or eliminate oxygen-deficient locations.

CONTROL POINT: Design, Operations, Maintenance

(10) Electrical Hazards.
Description: Operation of temporary and permanent electrical equipment, such as lights, generators, and soil washing/solvent extraction system components may cause electrical hazards.

Control: Controls for electrical hazards include

- Verify that the hazardous area classifications, as defined in NFPA 70-500-1 through 500-10, are indicated on the drawings.
- Verify that all controls, wiring, and equipment conforms to the requirements of EM 385-1-1, Section 11.G and NFPA for the identified hazard areas.
- Use grounded equipment and/or equipment with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1, Section 11 or NFPA 70 requirements.

CONTROL POINT: Design, Construction, Operations, Maintenance

(11) Emergency Wash Equipment Hazards.
Description: Emergency shower/eye wash equipment required by 29 CFR 1910.151 are not always equipped with adequate floor drains, thereby creating

potential electrical hazards or walking surface hazards during required testing/use.

Control: Controls for wash equipment hazards include

- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that may be hazardous when wet.

CONTROL POINT: Design

(12) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards

(1) Extracting Agents and Solvents.
Description: Workers may be exposed to VOC emissions from either extracting agents (surfactants and concentrated acids), solvents used in the solvent extraction process, or to wastes in the extraction/washing process. Examples of solvents include methyl ethyl ketone, pentane, and citric acid derivatives.

Control: Controls for chemical exposure include

- Add chemicals to the system under closed or properly ventilated conditions.
- Use respiratory protection (e.g., an air-purifying respirator with organic vapor cartridges) to control inhalation exposures.
- Assess the exposure (with exposure monitoring) to determine the type of respirator for the particular application.

CONTROL POINT: Design, Construction, Operations, Maintenance

(2) Chemical Release From System Malfunction.
Description: During system failure, workers may be exposed to either solvents or extraction agents if the system experiences a release from over-pressurization or other malfunction.

Control: A control to prevent system chemical release includes

- Use a system designed with redundant safety features including automatic warning systems to prevent a release of chemicals from over-pressurization or other malfunction.

CONTROL POINT: Design

(3) Chemical Exposure From Precipitation Chemicals or Sludge.
Description: During the process of treating water from the operation, workers may be exposed to chemical hazards from acidic or caustic precipitation chemicals or to the sludge generated from the process. Exposure may be through inhalation/dermal/ingestion routes. The sludge may contain heavy metals, including lead, or organic compounds such as fuels.

Control: Controls to prevent chemical exposure include

- Design a closed-feed system for the addition of precipitation chemicals as well as for sludge handling and removal.
- Use less toxic precipitation agents.
- Use personal protective equipment (PPE): nitrile gloves for dermal protection from fuels and an air-purifying respirator with combination HEPA (N100, R100, P100) filter/organic cartridges for control of inhalation hazards.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards

Radioactive Material.
Description: Radiological materials may be segregated in the soil washing process, and naturally occurring radioactive material (NORM) may be present in soils, sludge, and groundwater. Some radioactive materials may present an external hazard. All radioactive materials may present an internal exposure hazard through inhalation or ingestion.

Control: Controls for radioactive materials include

- Test soil, sludge, or groundwater to determine if radioactive materials are present.
- Consult a qualified health physicist if any radioactive material above background levels is found. Consultation should result in determination of exposure potential, any necessary controls, or required PPE.

CONTROL POINT: Design, Construction, Operations

d. Biological Hazards.

Biological Contaminants.
Description: At those sites involving medical wastes or sewage sludge, microorganisms in the soil may cause exposure hazards during the soil mixing and waste stabilization activities. Workers may be exposed to inhalation/ingestion/dermal contact with pathogens such as *Coccidioides sp., Histoplasma sp.,* and *Mycobacterium sp.* if contaminated dusts become airborne.

Control: Controls for biological contaminants include

- Reduce the generation of airborne microbe-contaminated dust with the periodic application of water, amended water, or emission-suppressing foams to the active excavation and mixing areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas where foam has been applied.
- Minimize the amount of soil agitation during mixing operations.
- Erect wind screens and use portable surface covers.
- Use proper types of PPE: an air-purifying respirator with HEPA (N100, R100, P100) filters.
- Offer frequent health and safety awareness meetings, use experienced workers, decontamination stations, and standard personal hygiene procedures.

CONTROL POINT: Design, Operations

Chapter 7
Soil Vapor Extraction (In Situ), Bioventing, Biodegradation, Thermally Enhanced Soil Vapor Extraction

7-1. General.

The process of soil vapor extraction (SVE), SVE enhancements, bioventing, and technology applications are included in this section. The second section of the chapter is a hazard analysis, including controls and control points.

7-2. Technology Description.

a. Soil Vapor Extraction Methods.

SVE is the process of extracting soil gas from the vadose zone (the vertical soil zone between the ground surface and the groundwater surface) to convey volatile organic compound vapors (VOCs) to the surface for collection or destruction. The process, illustrated in Figure 7-1, generally consists of wells screened in the unsaturated impacted zone above the water table. The wells are manifolded and connected to a vacuum blower capable of establishing a vacuum on the subsurface soils. The process relies on the combined effects of lowered soil gas pressure (partial vacuum) and soil gas mass flow (soil gas extraction) to enhance volatilization and mass removal of volatile compounds from soil and soil water. The process is dependent on the partitioning of VOCs into the soil gas from the water films and water table (Henry's Law) and/or from a separate phase on the pore space surfaces of the soils (Raoult's Law).

Many VOCs of environmental concern have low water solubility and relatively high vapor pressures, so they are extracted readily by the SVE process. Ancillary equipment is used to protect the pump and to treat the extracted soil gas (typically using vapor phase granular activated carbon or catalytic oxidation). Entry of fresh air can be effected by the installation of infiltration/ induction/ injection wells, or by general infiltration from the surface, or a combination of both.

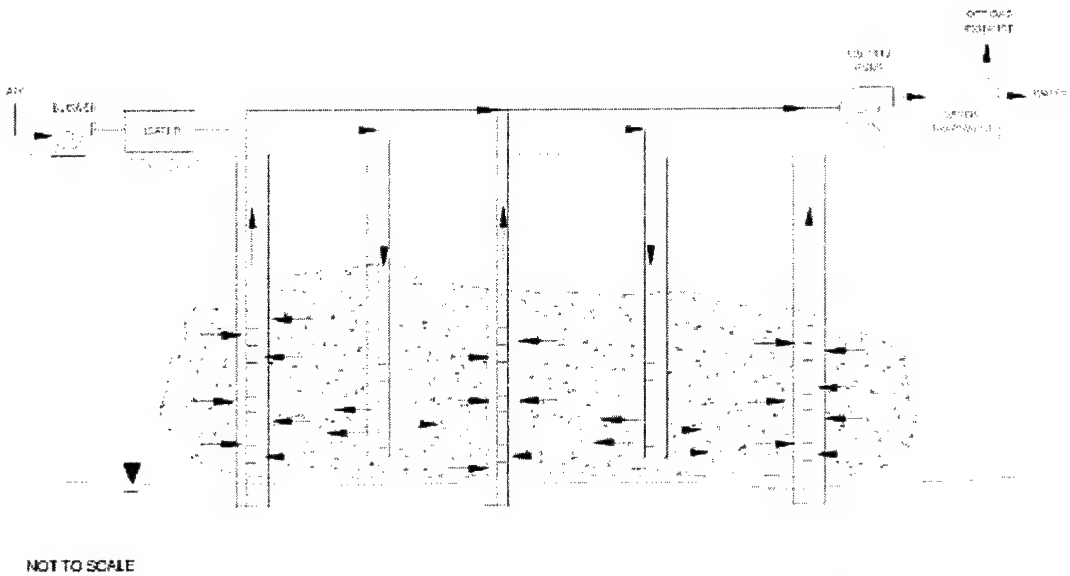


FIGURE 7-1. SVE (IN SITU)/THERMALLY ENHANCED SVE

b. SVE Thermal Enhancements.

SVE systems can be installed with accompanying sparging or air injection processes to enhance the soil gas movement. Occasionally the processes may also be enhanced in rate and extended to some semi-volatile organic compounds (SVOCs) by applying heat to the treatment zone. Heat application is most commonly performed by heating the air prior to its injection or by injecting steam into the subsurface. Since air has a much lower heat capacity than the soil and water it must heat, the rate of heating using air is generally slow. Steam can heat the soil much faster, but excessive heat can kill microorganisms that are degrading the VOC and/or SVOCs present (such as in bioventing). This effect can also alter the soil chemistry and structure, add water (steam condensate) to the soils, enhance mobilization of low solubility and/or low volatility contaminants, and thus (undesirably) mobilize them to the groundwater.

c. Bioventing (In-situ Biodegradation).

In-situ biodegradation, as related to SVE, is termed *bioventing* (Figure 7-2). Bioventing is the process of enhancing in-situ bioremediation of the contaminants in the soils by enhancing the availability of oxygen to the microbes by SVE-type venting processes. The primary parameters that can be altered are: oxygen content of the pore water, nutrient (nitrogen and phosphorus) content of the soil and water, and pH.

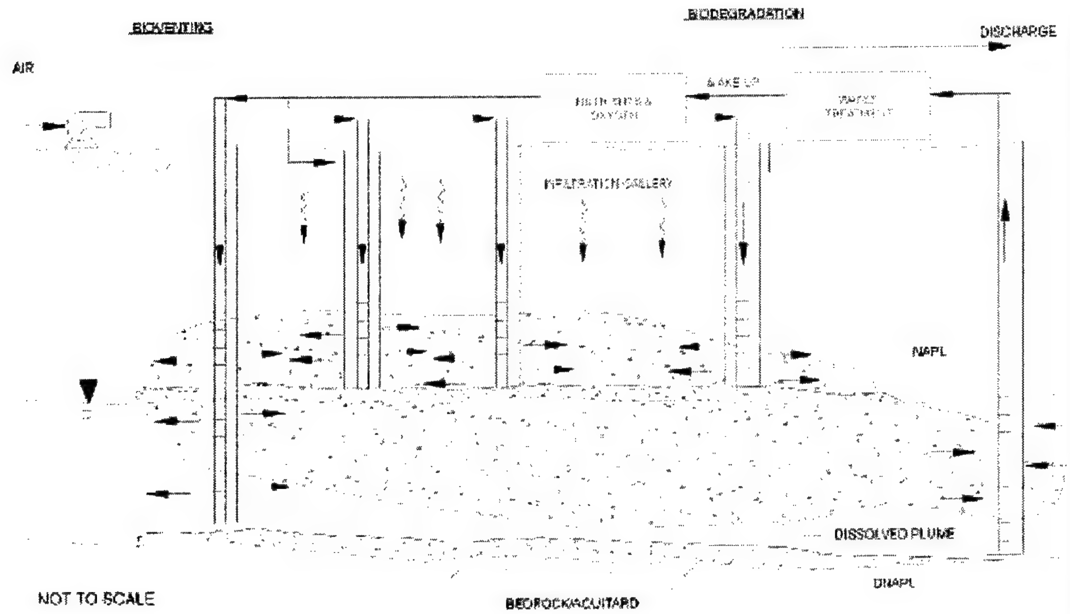


FIGURE 7-2. BIOVENTING/BIODEGRADATION

During bioventing, air drawn or injected into the subsurface provides oxygen to aerobic microorganisms that degrade the VOCs and SVOCs. Since the objective is to provide sufficient oxygen to microbes rather than to use air as a mass remover of VOCs, the rate of air flow is usually lower than with SVE; only the rate needed to sustain biological activity is required. Occasionally, nutrients and water may be added to the subsurface using infiltration galleries to optimize the biodegradation rate or in some cases can be delivered via air into the treatment zone. The degradation process produces carbon dioxide, water, and incompletely digested organic intermediates as the reaction products with the intermediate products subject to further microbial digestion.

d. Bioventing Enhancements.

These venting processes can be enhanced by active injection of air or by induction of air during active air extraction. The latter approach provides for better control of the off gas since active injection of air can cause contaminated soil gas to exit the soil surface, and radially flow through the soil in an uncontrolled manner.

e. Applications.

The processes will remove or biologically alter the chemical structure of many VOCs and SVOCs. Since they are in-situ processes, they minimize exposure to these compounds during the remediation. However, they require longer times to implement than soil removal technologies.

SVE effectively treats fuel component VOCs and chlorinated organic VOCs as well; bioventing effectively treats fuel, VOCs, and some SVOCs. Chlorinated compounds treated with SVE are treated at rates commensurate with their volatilities and solubilities. Chlorinated VOCs may be treated effectively by bioventing, but typically at a slower rate than comparable non-chlorinated organics. This is because the chlorinated compounds are more resistant to microbial metabolism due to the chlorine (trichloroethylene, perchloroethylene, and trichloroethane degrade slowly in bioventing).

7-3. Hazard Analysis.

Principal unique hazards associated with soil vapor extraction (in-situ)/bioventing/biodegradation/thermally enhanced soil vapor extraction, methods for control, and control points are described below.

a. Physical Hazards.

(1) Equipment Hazards (Excavation).
Description: During excavation of trenches during the installation of horizontal piping systems, workers may be seriously injured or killed by heavy equipment such as front-end loaders and scrapers operating in their work areas. This equipment may also generate excessive noise during operation.

Control: Controls for equipment hazards include
- Use heavy equipment with a backup alarm to alert workers.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Wear hearing protection.

CONTROL POINT: Construction, Operations, Maintenance

(2) Utility Contact Hazards.
Description: Fire or explosion hazards may exist if excavation equipment ruptures an underground utility (electrical or gas lines) during installation of the system.

Control: A control for utility hazards includes
- Identify the location of all below- and above-ground utilities by contacting local utilities and public works personnel. When there is any doubt or uncertainty, perform a utility survey, probe with a metal rod, or hand excavate to determine the exact location of utilities prior to drilling. Once utilities are located, careful excavation by backhoe may be allowed.

CONTROL POINT: Design, Construction

(3) Fire and Explosion Hazards (Gas Transfer).
Description: During the transfer of flammable gas from the extraction wells or subsurface piping systems to the treatment unit, a fire or explosion hazard may exist. The gas may be ignited by improperly selected or installed equipment.

Control: Controls for fire and explosion hazards during gas transfer include

- Verify that the hazardous area classifications, as defined in NFPA 70-500-1 through 500-10, are indicated on the drawings.
- Use controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11.G and NFPA 70 for the identified hazard areas.
- Use grounded equipment and/or equipment with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1, Section 11 or NFPA 70 requirements.
- Monitor the atmosphere periodically around the area with a combustible gas monitor. If the concentration of explosive gas reaches 10 percent of the Lower Explosive Level (LEL) or greater, inspect the system for leaks and emission points.
- Control all sources of VOC emissions to prevent the release of flammable gas.
- Install a permanent explosion level meter/alarm if necessary.

CONTROL POINT: Design, Construction

(4) Explosion Hazards (Steam Generator).
Description: Thermally enhanced SVE systems may incorporate the use of steam to heat soils. Pressure caused by plugged steam lines may cause a rupture or an explosion in the system.

Control: Controls for explosion due to steam generators include

- Operate the steam generator within its design parameters and use emergency pressure relief valves.
- Flush steam lines periodically to remove any accumulated scale or deposits.

CONTROL POINT: Design, Operations, Maintenance

(5) Burn and Freezing Hazards.

Description: The surface temperature of uninsulated steam generators and piping systems may reach several hundred degrees and pose a burn hazard to workers. Catalytic oxidation system components can be quite hot, and also pose a burn hazard. Cryogenic systems, associated with O_2 delivery systems, can have very cold surfaces and pose a contact freezing hazard.

Control: Controls for burn and freezing hazards include

- Insulate surfaces properly.
- Include hazard warning signs on the equipment.
- Provide physical covers to prevent contact.

CONTROL POINT: Design, Construction, Operations, Maintenance

(6) Noise Hazards.
Description: High levels of noise may be generated by blowers and compressors and may result in hearing loss.

Control: Controls for noise hazards include

- Use insulated materials, barriers, and properly lubricate and maintain equipment.
- Require personal hearing protection when working in areas of elevated noise levels.

CONTROL POINT: Design, Operations

(7) Unguarded Moving Equipment.
Description: Unprotected blowers and fans may entangle workers' clothing and cause injury.

Control: Controls for moving equipment include

- Guard all moving and rotating equipment.
- Inform workers that all such equipment must be operated with guards in place.
- Train workers in the entanglement hazards.
- Discourage the wearing of loose-fitting clothing.

CONTROL POINT: Design, Operations

(8) Equipment Hazards (Drilling).
Description: During drilling operations, heavy equipment such as augers and pipes are periodically raised overhead and placed into or above the well. Workers may be exposed to swinging equipment during lifting or may be exposed to crushing hazards if the equipment falls. Cables used to raise and lower equipment may also become entangled in loose clothing or other equipment. Direct push drilling methods using hydraulic pressure to advance a soil boring may pose a crushing hazard to hands and/or feet.

Control: Controls for equipment hazards during drilling include

- Post an observer to the side to observe and supervise when raising a drill mast.
- Do not move the drilling rig with the mast raised.

- Secure all loose clothing, use low-profile auger pins, and use long-handled shovels to remove soil cuttings from the borehole.
- Use cable systems with caution and inspect regularly for loose strands or frayed wires that may become entangled in loose clothing.

CONTROL POINT: Design, Maintenance

(9) Electrocution/Fire Hazards (Overhead Lines or Piping Systems).
Description: Electrocution or fire hazards may exist when using hollow-stemmed auger, direct push, or other drilling methods if the drilling mast contacts overhead electric lines or piping systems containing flammable chemicals.

Control: Controls for electrocution include

- Inform all workers as to the location of overhead utilities.
- Drill in an alternative location if possible.
- Keep all lifting equipment (cranes, forklifts, and drilling rigs) at least 10 feet from the power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.E.
- Post a worker to observe and supervise when raising a drill mast.
- Operate the mast at its lowest height; different drill rigs have different mast elevations and may be operated at different heights.

CONTROL POINT: Design, Construction, Maintenance

(10) Electrical Equipment Hazards.
Description: Operation of temporary and permanent electrical equipment, such as lights, generators, and heated SVE system components, may cause electrical hazards.

Control: Controls for electrical equipment include

- Verify that the hazardous area classifications as defined in NFPA 70-500-1 through 500-10 are indicated on the drawings.
- Use all controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11.G and NFPA 70 for the identified hazardous areas.
- Use grounded equipment and/or equipment provided with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1, Section 11 or NFPA 70 requirements.

CONTROL POINT: Design, Construction, Operations, Maintenance

(11) Explosion Hazards (Gas Storage).
Description: Improper storage and use of cylinders of compressed gases in some bioventing systems may cause explosive or projectile hazards.

Control: Controls for explosion due to gas storage include

- Store cylinders of compressed gases upright, capped, and secured to prevent movement.
- Avoid extreme temperatures.

CONTROL POINT: Design, Operations

(12) Steam Pressure Washing.
Description: Steam pressure washing of equipment may expose workers to thermal or burn hazards, eye hazards due to flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control: Controls for steam pressure washing include

- Use insulated gloves (e.g., silica fabric gloves).
- Wearing safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(13) Muscle Injuries.
Description: Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control: Controls for muscle injuries include

- Do not require workers to lift heavy loads manually.
- Use proper lifting techniques including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385-1-1, Section 14.A). Some loads may require two people.
- Use mechanical lifting equipment to lift or to move loads.

CONTROL POINT: Design, Construction, Operations, Maintenance

(14) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards

(1) Degradation Products.
Description: Biological degradation of certain organic compounds may produce toxic intermediate products. As an example, degradation of trichlorethylene (TCE) can produce dichloroethylene (DCE) and vinyl chloride (VC). Vinyl chloride exists as a gas and may accumulate to higher levels in boreholes or in the system. Workers may be exposed to the degradation products during operation or maintenance of the system.

Control: Controls for degradation products include
- Ventilate the area to minimize exposure.
- Require air-supplied respiratory protection if supported by air monitoring results. (Note: air-purifying respirators are not recommended for vinyl chloride).
- Remediation designers: understand and anticipate the generation and management of general and specific process products such as carbon dioxide, hydrogen sulfide, vinyl chloride (CO_2, H_2S, VC) and design for their management.

CONTROL POINT: Design, Operations, Maintenance

(2) Waste Chemicals and VOC Exposure.
Description: During installation of the wells and system operations and maintenance, workers may be exposed to dermal or inhalation hazards associated with waste chemicals, such as airborne dusts, particulates, and VOC emissions resulting from off gassing or leaks.

Control: Controls for waste chemicals and VOCS include
- Apply water or surfactant amended water solution to the area during installation to help control generation of airborne dusts, particulates, and VOCs.
- Use proper ventilation during installation and operation.
- Use personal protective equipment (PPE) that eliminates exposure hazards (e.g., an air-purifying respirator with organic vapor cartridges).
- Check closed systems, such as SVE, routinely for leaks of the off-gas treatment system with PIDs, air samples, O_2 meters, leak

detection fluids, explosive gas meters, or specific gas tests with chemical-specific detector tubes.

- Repair leaks immediately.
- Make vent stack heights adequate to disperse off gas.
- Designers: anticipate byproducts and products and be certain that technologies selected for treatment (e.g., activated carbon, condensation, catalytic oxidation) of off-gas residuals are both effective and safe.

CONTROL POINT: Design, Construction, Operations, Maintenance

(3) VOC Migration.
Description: Air injection may cause the migration of VOCs to low areas, such as basements, sewers, and other areas. The accumulated, flammable VOCs can cause an explosion or chemical exposure to the occupants.

Control: A control for VOC migration includes

- Test air periodically to ensure safe levels in basements and other areas where VOCs may migrate.

CONTROL POINT: Design, Operations, Maintenance

(4) VOC Exposure (Vents).
Description: Workers may be exposed to VOCs as they are discharged from the blower vent.

Control: Controls for VOC migration include

- Install emission controls, such as activated carbon canisters, on the blower vent discharge.
- Monitor periodically for efficiency.

CONTROL POINT: Design, Operations, Maintenance

(5) Chemical Release.
Description: Fire and/or explosion or chemical release (inhalation/ingestion/asphyxiation) hazards may exist when using hollow-stemmed auger, direct push, or other drilling methods if the drilling bit or bucket ruptures underground utilities, tanks, or piping systems (overhead chemical feed lines) containing hazardous chemicals.

Control: Controls for accidental chemical release include

- Identify location of all below ground utilities by contacting local utilities during design phase.
- Perform a utility survey, probe with a metal rod prior to excavation, or hand excavate to determine the exact location of underground lines prior to drilling.

- Locate overhead hazards and design so that installations using erect equipment are not necessary in that area, if possible.

CONTROL POINT: Design, Construction

c. Radiological Hazards

Radon Exposure.
Description: In some geological settings, workers may be exposed to naturally occurring radon gas. The gas is drawn from the soil in the SVE stream. Radon gas and radon progeny do not present a significant external hazard. While breakdown products of radon (progeny) may present an inhalation/ingestion hazard, quantities of radon progeny normally present would not pose a significant exposure hazard.

Control: Controls for radon exposure include

- Operate emission control technologies properly to limit exposure to acceptable levels.
- Consult a qualified health physicist if excessive levels are encountered or suspected.

CONTROL POINT: Design, Operations, Maintenance

d. Biological Hazards

(1) Biological Contaminants.
Description: At those sites involving medical wastes or sewage sludge, microorganisms in the soil may cause exposure hazards during system installation activities. Workers may be exposed to inhalation/ingestion/dermal contact with pathogens such as *Coccidioides sp., Histoplasma sp.,* and *Mycobacterium sp.* if contaminated dusts become airborne.

Control: Controls for biological contaminants include

- Reduce the generation of airborne microbe-contaminated dust with the periodic application of water, surfactant amended water, or emission-suppressing foams to the active excavation/drilling areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas where foam has been applied.
- Erect wind screens and use portable surface covers.
- Use the proper types of PPE: an air-purifying respirator with HEPA (N100, R100, P100) filter/cartridge and rubber gloves.
- Use experienced workers, repeated health and safety meetings, decontamination stations, and other standard procedures.

CONTROL POINT: Construction, Maintenance

(2) Pests.
Description: Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus.

Control: Controls for pests include

- Perform periodic inspections of the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents for exposure control. Workers should check their skin and clothing for ticks periodically.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 8
Free-Product Recovery

8-1. General.

Chemical contaminants usually existing as free product and methods of removal are described in the first section of the chapter. The chapter's second section is a hazard analysis with controls and control points listed.

8-2. Technology Description.

a. Compound Types

Many contaminants, usually hydrophobic organics, when released in sufficient volume, will exceed the absorption capacity of the intervening soils and flow down to the groundwater surface through the soil pore spaces. If less dense than water, the materials will float on the groundwater, slightly depressing the surface tension in a potentially recoverable pool. If denser than water, the materials will continue to sink through the pore spaces (displacing water) forming discrete and connected ganglia, and later possibly reaching a lower retarding layer.

The most prevalent classes of compounds likely to exist as free product or non-aqueous phase liquids (NAPLs) include those compounds with low solubilities in water such as chlorinated solvents, reagents (e.g., trichloroethylene, tetrachloroethylene, and PCBs), and petroleum hydrocarbons (e.g., gasoline, jet fuel, fuel oils, and tars). Chlorinated solvents and tars are typically more dense than water and are called DNAPL (dense non-aqueous-phase liquid). Petroleum hydrocarbons are generally less dense than water and are called LNAPL (light non-aqueous-phase liquid). DNAPLs tend to sink vertically. They will often migrate deep underground into isolated areas where it may be impossible to remove them by conventional treatments. LNAPLs float on the water table and tend to spread laterally at the top of the capillary fringe.

b. Removal Methods.

Free product, such as oil or NAPLs, on groundwater may be removed using three methods:

- Open trenches
- Back-filled trenches with recovery wells
- Extraction wells

Water table depth and gradient are the primary factors in selecting a recovery method. Schematics of one-pump and two-pump recovery well systems are presented in Figures 8-1, 8-2, and 8-3.

The effectiveness of any free-phase product recovery system requires a good understanding of geologic conditions. Limitations on the rate of recovery include water, free-phase handling capabilities, and site-specific factors.

Recovery trenches can be used to remove LNAPL when the groundwater depth is shallow enough to reach with a trench. LNAPL recovery devices can be installed into the trench to recover free product. A groundwater pump may be used to depress the local groundwater and increase the rate of oil and water flow to the trench. An impermeable barrier(s) (e.g., bentonite or clay slurry wall) can be installed to divert liquid flow towards the trench.

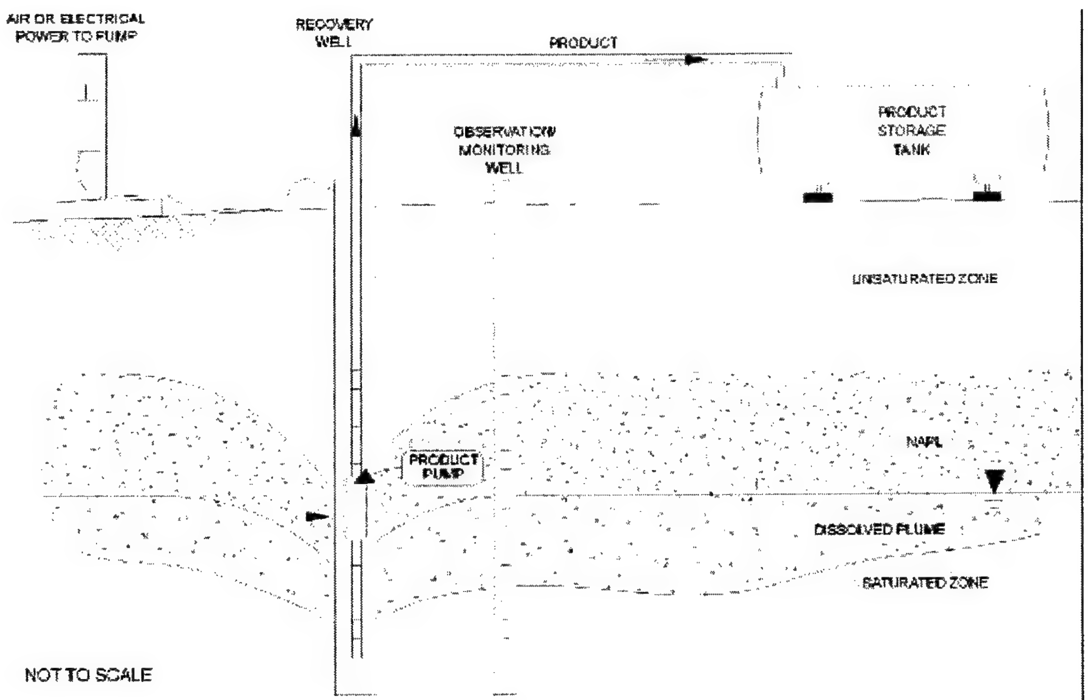


FIGURE 8-1. FREE-PRODUCT RECOVERY(ONE-PUMP SYSTEM)

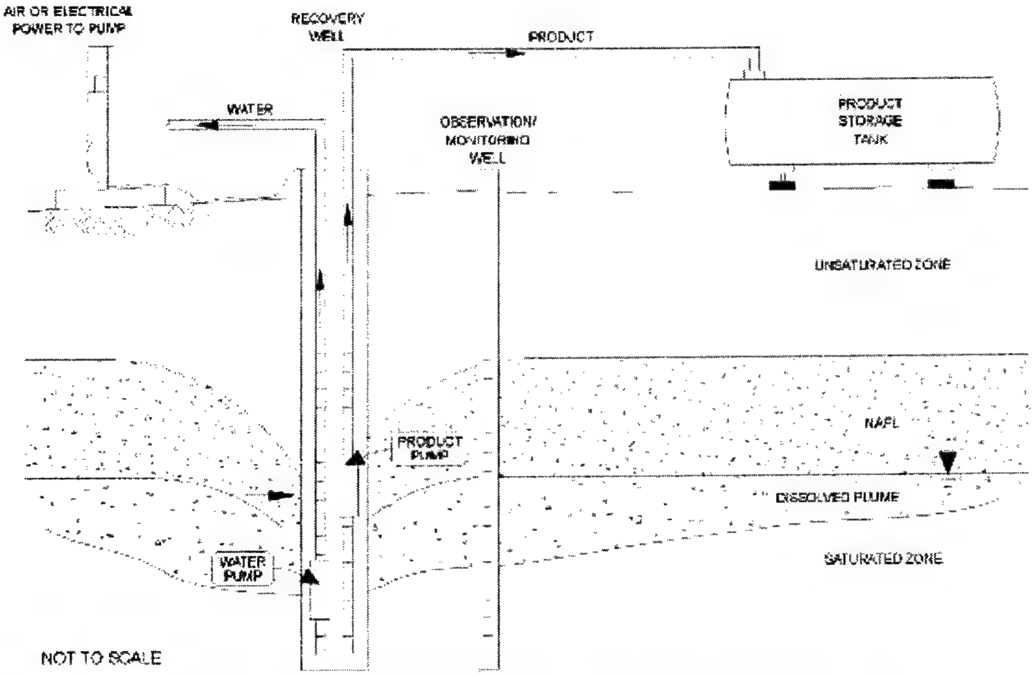


FIGURE 8-2. FREE-PRODUCT RECOVERY(TWO-PUMP SYSTEM)

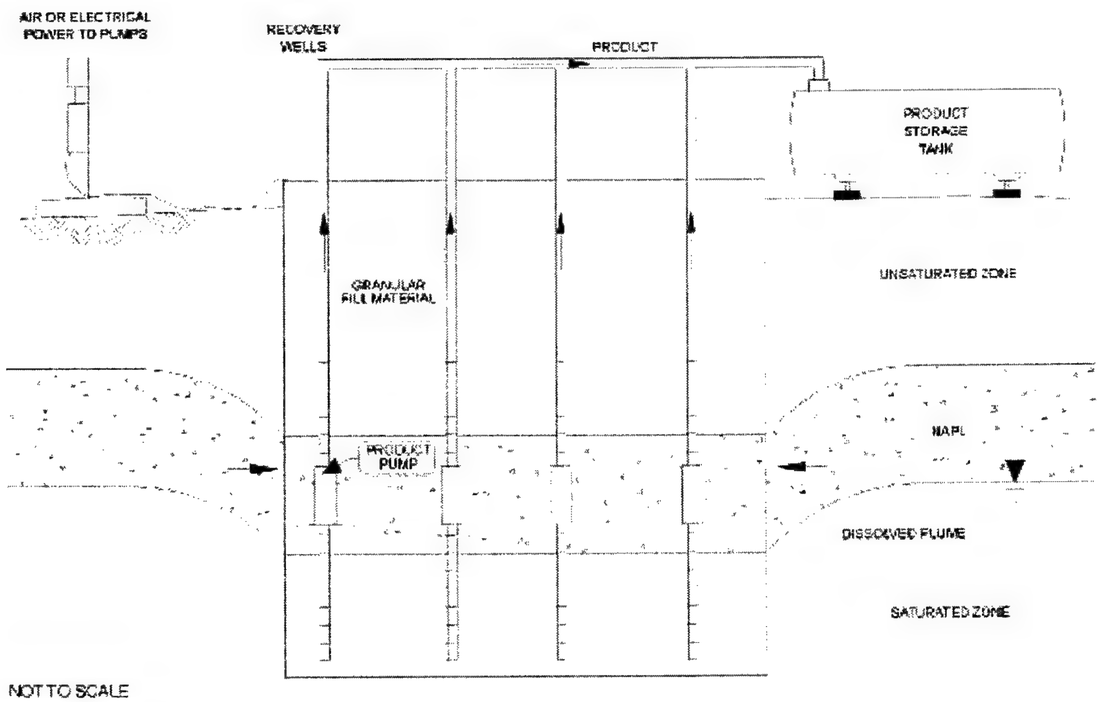


FIGURE 8-3. FREE-PRODUCT RECOVERY TRENCH

Extraction (recovery) wells also may be used for product recovery. Slurry walls can be used to guide the groundwater and product flow to the well(s). LNAPL in the well can be removed with a product skimmer pump or belt skimmer, vacuum devices (slurpers), or a groundwater recovery pump. A groundwater pump creates a cone of depression, which can increase the oil recovery rate, but can also emulsify water and LNAPLs. Recovery wells can be single pump, double pump, or double shaft. A single-pump well uses one pump to recover oil and water. Double-pump wells combine a product recovery device (pump) with a groundwater drawdown pump into a single well. A double-shaft well uses two concentric casings in one well. Free product is recovered in the outer casing while groundwater is drawn down by another pump in the inner casing. This separation of devices allows better regulation of water level and flow within the well, and helps minimize emulsion of oil and water.

For DNAPL recovery, the pool of sinking product must be located (if present); the lower retarding strata delineated for low points where the DNAPL has flowed; and those low points penetrated by recovery wells and pumps to capture NAPL. This is usually a slow process, but may be enhanced by groundwater recovery and reinjection with or without surfactants.

8-3. Hazard Analysis.

Principal unique hazards associated with free-product recovery, methods for control, and control points are described below.

a. Physical Hazards

(1) Fire or Explosion Hazards (Drilling).
Description: Soil boring using hollow-stemmed augers prior to well installation may cause a fire or explosion during drilling into soils saturated with flammable and/or combustible materials under unusual or extraordinary conditions. Sparks generated when an auger contacts rocks, metal, or other underground objects may ignite a flammable atmosphere inside the bore hole. This is considered an unlikely but potential hazard.

Control: A control for fire or explosion hazards includes

- Use mud or water rotary drilling methods, which add moisture to the cutting area.

CONTROL POINT: Construction, Maintenance

(2) Utility Contact Hazards.
Description: Fire, explosion, or electrocution hazards may exist when using hollow-stemmed auger drilling methods if the rotating auger contacts or ruptures underground utilities (electrical or gas lines) or comes in contact with overhead electric lines.

Control: Controls for utility contact hazards include

- Contact local utilities and public works personnel to determine the locations of all utilities. When there is any doubt or uncertainty, perform a utility survey, probe with a metal rod, or hand excavate to determine the exact location of utilities prior to drilling. Once utilities are located, careful drilling may be allowed.
- Post an observer to the side to supervise when raising a drill mast.
- Do not move the drilling rig with the mast raised.

CONTROL POINT: Design, Construction, Maintenance

(3) Fire and Explosion Hazards (Transfer of Flammable Liquid).
Description: During the transfer of flammable or combustible liquids (such as jet fuel) from the recovery well, a fire or explosion hazard may exist. The liquid may be ignited by improperly selected or installed equipment. Emissions from the collection equipment may also be ignited, possibly causing a fire or explosion. Ejector pumping systems produce mixtures of flammable vapors and air, which may ignite and explode.

Control: Controls for fire and explosion hazards include

- Verify that the hazardous area classifications, as defined in NFPA 70-500-1 through 500-10, are indicated on the drawings.
- Use controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11.G and NFPA 70 for the identified hazard areas.
- Check electrical system design and equipment installation for appropriateness to hazard areas.
- Use grounded equipment and/or equipment provided with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1 or NFPA 70 requirements.
- Do not use piping systems and ejectors that mix air with flammable vapors.

CONTROL POINT: Design, Construction, Operations, Maintenance

(4) Equipment Hazards.
Description: During installation of the extraction trenches, workers may be seriously injured or killed by heavy equipment such as front-end loaders and backhoes. Heavy equipment may also generate elevated noise levels, which may damage worker hearing.

Control: Controls for equipment hazards include

- Use heavy equipment with a backup alarm to alert workers.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Wear hearing protection.

CONTROL POINT: Construction, Maintenance

(5) Trench Hazards.
Description: Walls of trenches used for free-product recovery may collapse, causing workers to fall into the excavation.

Control: Controls for trench hazards include
- Ask a competent person to determine the integrity of the excavation before workers are allowed to walk near the edge of the excavation.
- Do not approach the edge of the excavation without fall protection.
- See EM 385-1-1, Section 25.B for additional control measures and requirements.

CONTROL POINT: Design, Construction, Maintenance

(6) Unguarded Moving Equipment.
Description: Skimmer belts used for free-product removal from trenches are often equipped with unguarded pulleys, which may cause entanglement of loose clothing.

Control: Controls for moving equipment include
- Use guarded pulleys and guarded moving or rotating mechanical devices.
- Train workers to operate the equipment only with the machine guarding in place.
- Discourage the wearing of loose clothing.

CONTROL POINT: Design, Construction, Operations, Maintenance

(7) Fire or Explosion Hazards (Tanks).
Description: Containment tanks used for storage of recovered free product may overflow, creating the potential for fire or explosion.

Control: Controls for tanks include
- Install fluid level indicators equipped with automatic shut-off switches on free-product recovery tanks to help prevent overflowing.
- Inspect the collection equipment regularly to identify and repair system leaks.

CONTROL POINT: Design, Operations, Maintenance

(8) Steam Pressure Washing.
Description: Steam pressure washing of equipment may expose workers to thermal or burn hazards, eye hazards due to flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control: Controls for steam pressure washing include
- Use insulated gloves (e.g., silica fabric gloves).
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.

- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(9) Muscle Injuries.
Description: Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control: Controls for muscle injuries include

- Do not require workers to lift heavy loads manually.
- Use proper lifting techniques including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385-1-1, Section 14.A).
- Use mechanical lifting equipment to lift or to move loads.

CONTROL POINT: Design, Construction, Operations, Maintenance

(10) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Vapor Discharge.
Description: Vapors discharged from oil/water separators may expose workers to VOCs via an inhalation exposure.

Control: A control for vapor discharge includes

- Vent the discharge from the oil/water separators above the breathing zone of workers.

CONTROL POINT: Design

(2) Chemical Exposure.
Description: Process and equipment piping for the collection, transfer, treatment, and storage of recovered free product may leak and create an exposure pathway either by ingestion/inhalation/dermal contact for workers operating or maintaining the system. Workers may be exposed to waste materials, such as benzene in gasoline or other hydrocarbons in jet fuel. The exposure may cause skin, eye, and respiratory tract irritation and other symptoms.

Control: Controls for chemical exposure include
- Prevent leaks through regular system inspection and maintenance.
- Detect leaks by a regular leak detection process using O_2 meters, explosivity meter, PIDs, OVA, leak detection fluids, and other appropriate methods.
- Wear personal protective equipment (PPE) such as an air-purifying respirator with organic vapor cartridges and nitrile gloves for skin exposure to gasoline.

CONTROL POINT: Operations, Maintenance

(3) Contaminants (Trench/Well Installation).
Description: During trench and/or well installation, workers may be exposed to contaminants, such as VOCs, dusts, and metals in soil and development water through inhalation/ingestion/dermal contact routes.

Control: Controls for contaminants include
- Apply water or an amended water solution to the area during well and trench installation to help control the generation of airborne dusts, particulates, and VOCs.
- Use respiratory protection including an air-purifying respirator equipped with approved filter/cartridges such as HEPA (N100, R100, P100) filters for particulates, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Analyze work tasks and potential for chemical exposure to determine the correct PPE and/or respirator cartridge(s). The analysis should include a chemical waste profile to help ensure that PPE specified will be appropriate for the respective chemical hazard(s).

CONTROL POINT: Construction, Operations, Maintenance

(4) Contaminants (Free-Product Recovery and Collection).
Description: During operation of the free-product recovery trenches and collection equipment, workers may be exposed to chemical materials, such as jet fuel, hydrogen sulfide, VOCs, and biologically generated byproducts (e.g., vinyl chloride, methane).

Control: Controls for contaminants include

- Wear respiratory protection (e.g., an air-purifying respirator with organic vapor cartridges) to control inhalation exposures to VOCs during operation of collection equipment.
- Analyze the type of respirator required before issuing PPE. Include a chemical waste profile on the waste materials to ensure that the respirator and filter/cartridge specified will be appropriate.

CONTROL POINT: Operations, Maintenance

c. Radiological Hazards.

Radioactive Materials.
Description: Radioactive materials may have been buried or naturally occurring radioactive material (NORM) may be present in soils, sludge, and groundwater. Radioactive materials may become entrained with the free product and eventually build up as scale in pipes and handling systems. Some radioactive materials may present an external exposure hazard. All radioactive materials may present an internal exposure hazard through inhalation or ingestion. Exposure to radiation using this remediation technology may be rare.

Control: Controls for radioactive materials include

- Test soil, sludge, or groundwater to determine if radioactive materials are present.
- Consult a qualified health physicist if any radioactive material above background levels is found to determine exposure potential and any necessary engineered controls or PPE.

CONTROL POINT: Design, Construction, Operations, Maintenance

d. Biological Hazards.

No unique hazards are identified.

Chapter 9
Dual-Phase Extraction (Bioslurping)

9-1. General.

The processes of dual-phase extraction and bioslurping are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

9-2. Technology Description.

Water immiscible contaminants (hydrophobic), such as many hydrocarbons and chlorinated hydrocarbons, can sink through the soil pore spaces to groundwater. When less dense than groundwater, the materials float in a spreading layer, depressing the groundwater surface tension slightly. Typical recovery is by a down-hole pump in a well. Material recovered is a mixture of hydrocarbons and groundwater.

a. Dual-Phase Extraction.

Dual-phase extraction modifies the typical design for well construction and groundwater non-aqueous phase liquids (NAPL) recovery methods by the insertion of a vacuum extraction pipe ("straw") down the well casing bore to the water table surface. The well head is sealed, and the extraction pipe is connected to a vacuum pump (capable of drawing a relatively high vacuum >0.5 atm) at the surface. The pump draws a mixture of air, water, and/or NAPL from the water surface by aspirating the liquid into the soil gas stream. The mixture of air, water, and NAPL is low in average density, which allows this extraction technique to be used at depths greater than an atmosphere pressure of water head. The two (or three) phases are separated on the surface in a series of separators, first liquid/vapor and then oil/water separators if needed. The soil gas replenishment is from the surrounding formation and eventually the surface so the process effectively aerates the vadose zone around the well. This can be used for biological enhancement, leading to the term "bioslurping." The process is illustrated in Figure 9-1.

b. Bioslurping.

The aeration of the vadose zone around the well can be used for biological enhancement or *bioslurping.* The three-phase flow (the combination of air and water flow above and below the NAPL) assists in pulling the NAPL into the well bore at a rate often exceeding conventional liquid pumping methods. The method may permit more effective dewatering of very tight soil formations. The method is applicable to NAPL sites and vadose zone contamination by volatile organic carbon compounds (VOCs) and degradable semi-volatile organic compounds (SVOCs). In bioslurping, the process is operated as described above, except the air and water movement are exploited to promote in-situ bioremediation during free-product recovery. This is occasionally done by reinjecting and reinfiltrating the recovered groundwater but with oxygen and nutrients added. This, in combination with the movement of unsaturated

zone air, provides bioventing and closed loop groundwater in-situ bioremediation. Thus, bioslurping is a combination of free-product recovery, bioventing, and in-situ bioremediation.

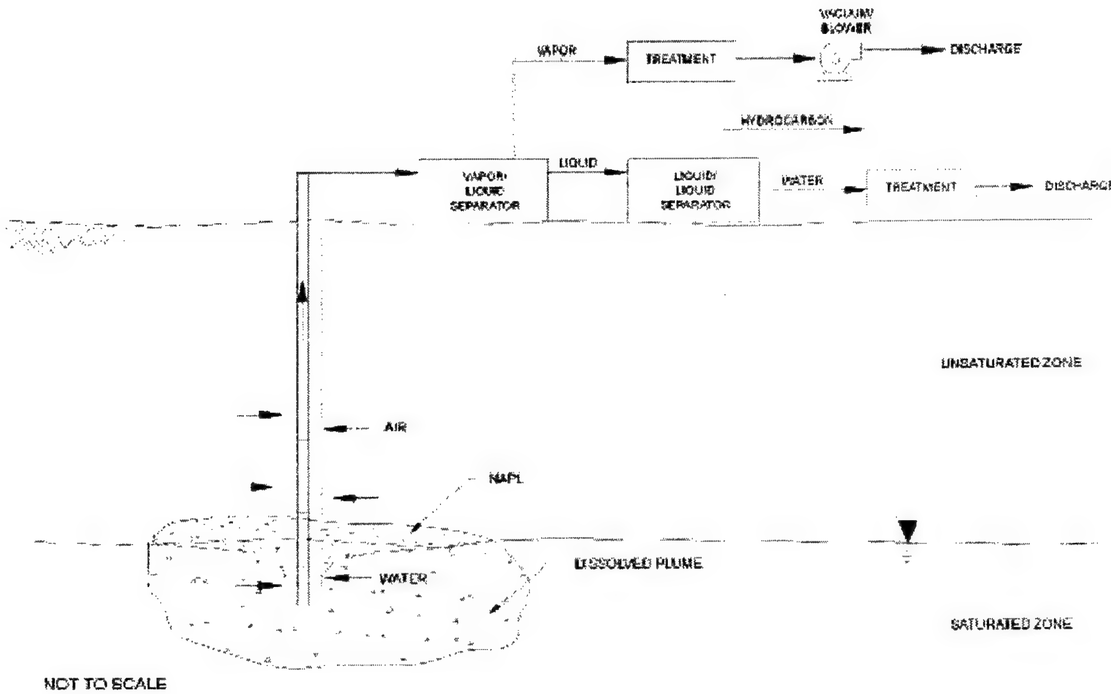


FIGURE 9-1. DUAL-PHASE EXTRACTION/BIOSLURPING

9-3. Hazard Analysis.

Principal unique hazards associated with dual-phase extraction (bioslurping), methods for control, and control points are described below.

a. Physical Hazards

(1) Fire and Explosion Hazards (Drilling).

Description: Soil boring using hollow-stemmed augers may cause a fire or explosion during drilling into soils saturated with flammable or combustible materials in unusual or extraordinary conditions. Sparks generated when a metal auger strikes against rocks, metal, or other underground objects may ignite a flammable atmosphere inside the bore hole.

Control: A control for fire/explosion includes

- Use methods such as mud or water rotary drilling, which add moisture to the cutting area.

CONTROL POINT: Design, Construction

(2) Utility Contact Hazard.
Description: Fire, explosion, or electrocution hazards may exist during hollow-stemmed auger drilling if the rotating auger contacts and ruptures underground utilities such as electrical and/or gas lines or comes in contact with overhead electric lines.

Control: Controls for utility contact hazards include

- Contact local utilities and public works personnel to determine the locations of all utilities. When there is any doubt or uncertainty, perform a utility survey, probe with a metal rod, or hand excavate to determine the exact location of utilities prior to drilling. Once utilities are located, careful excavation by backhoe may be allowed.
- Post an observer to the side to guide when raising a drill mast.
- Do not move the drilling rig with the mast raised.

CONTROL POINT: Design, Construction

(3) Fire and Explosion Hazards (Transfer of Flammable Gas/Liquids).
Description: During the transfer of extracted flammable or combustible liquids (such as jet fuel) and gas from the recovery wells, a fire or explosion hazard may exist. The liquid or gas may be ignited by equipment or from the discharge of static electricity.

Control: Controls for fire and explosion hazards include

- Verify that the hazardous area classifications, as defined in NFPA 70-500-1 through 500-10, are indicated on the drawings.
- Use all controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11.G and NFPA 70 for the identified hazard areas.
- Check for appropriate design and installation of equipment.
- Use grounded equipment and/or equipment provided with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1, Section 11 or NFPA 70 requirements.

CONTROL POINT: Design, Construction, Maintenance

(4) Fire and Explosion Hazards (Recovery Tank).
Description: If the product recovered by the technology is a flammable or combustible liquid (such as jet fuel), a fire or explosion hazard may exist with the product recovery tank.

Control: A control for fire or explosion in the recovery tank includes
- Use controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11.G and NFPA 70 for the identified hazard.

CONTROL POINT: Design, Construction, Maintenance

(5) Fire and Explosion Hazards (Emissions/Flammable Vapors).
Description: Emissions from collection equipment may be ignited, possibly causing a fire or explosion. In addition, ejector pumping systems produce mixtures of flammable vapors and air that may be ignited and result in an explosion.

Control: Controls for fire or explosion due to emissions include
- Perform regular inspections of the collection equipment to identify and repair system leaks.
- Do not use piping systems and ejectors that mix air with flammable vapors.

CONTROL POINT: Design, Operations, Maintenance

(6) Equipment Hazards (Drilling).
Description: Loose clothing may become entangled in cables used to raise and lower drilling tools and equipment or on other equipment. Direct push drilling methods using hydraulic pressure to advance a soil boring may pose a crushing hazard to hands and/or feet.

Control: Controls for equipment hazards due to drilling include
- Use cable systems with caution and inspect regularly for loose strands or frayed wires that may entangle loose clothing.
- Prohibit the wearing of loose fitting clothing.
- Keep hands and feet away from hydraulic push equipment.

CONTROL POINT: Construction, Operations, Maintenance

(7) Rotating Equipment.
Description: The rotating auger of a drill rig poses a hazard to workers as loose clothing may become entangled with the revolving auger.

Control: Controls for rotating equipment include
- Prohibit the use of loose clothing.
- Use low-profile auger pins.

- Use long-handled shovels to remove soil cuttings from the borehole.

CONTROL POINT: Construction, Maintenance

(8) Fire or Explosion (Containment Tank).
Description: Containment tanks used for storage of recovered free product may overflow, creating the potential for fire or explosion.

Control: Controls for fire/explosion due to containment tanks include
- Use NFPA-approved fluid level indicators appropriate for the fuels encountered.
- Install indicators on free-product recovery tanks to help prevent overflowing.
- Conduct regularly scheduled tank inspections.

CONTROL POINT: Design, Operations, Maintenance

(9) Fire Hazard (Piping Systems).
Description: Piping systems that become plugged may induce failure of the vacuum pump, causing an electrical fire.

Control: A control for fire due to piping systems includes
- Inspect and clean piping systems periodically to help prevent buildup of material that may cause blockage.

CONTROL POINT: Design, Operations, Maintenance

(10) Heat Stress.
Description: Workers may be exposed to elevated temperatures due to excess heating of blowers and other process equipment. The exposure may induce heat stress.

Control: Controls for heat stress include
- Use the correctly sized blowers, motors, and other equipment to prevent overheating.
- Train workers in heat stress symptoms and prevention.

CONTROL POINT: Design, Maintenance

(11) Explosion (Separators).
Description: Separators that generate flammable vapors may explode if ignited.

Control: Controls for explosion due to separators include
- Verify that the hazardous area classifications, as defined in NFPA 70-500-1 through 500-10, are indicated on the drawings.
- Use controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11.G and NFPA 70 for the identified hazard areas.

- Use grounded equipment and/or equipment provided with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1, Section 11 or NFPA 70 requirements.
- Permit only trained, experienced workers to work on the systems.
- Ventilate areas adequately to help prevent the accumulation of flammable gases.
- Include appropriate lockout/tagout equipment and procedures in the O&M of the system.
- Provide fire extinguishers rated for energized electrical systems where electrical equipment is installed and operated.

CONTROL POINT: Design, Operations, Maintenance

(12) Steam Pressure Washing.
Description: Steam pressure washing of equipment may expose workers to thermal or burn hazards, eye hazards due to flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control: Controls for steam pressure washing include
- Use insulated gloves (e.g., silica fabric gloves).
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(13) Blower Hazards.
Description: High levels of noise may be generated by blowers and compressors and may result in hearing loss. Unguarded blowers and fans may entangle workers' clothing, causing injury.

Control: Controls for blower noise and unguarded movement include
- Control equipment noise with insulation, barriers, and proper equipment lubrication and maintenance.
- Use hearing protection around elevated noise levels.
- Use guards on all moving and rotating equipment.
- Inform workers that guards must be in place for equipment operation.

CONTROL POINT: Design, Operations

(14) Muscle Injuries.
Description: Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control: Controls for muscle injuries include
- Do not require workers to lift heavy loads manually.

- Use proper lifting techniques including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385-1-1, Section 14.A).
- Use mechanical lifting equipment to lift or to move loads.

CONTROL POINT: Design, Construction, Operations, Maintenance

(15) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Liquid Waste Materials.
Description: Piping systems may leak from over-pressurization and spray workers with liquid waste materials. As a result, workers may be exposed through the inhalation/ingestion/dermal contact routes.

Control: Controls for liquid waste materials include

- Conduct regular system inspections, testing, and maintenance to prevent or minimize leaks and resulting exposures.
- Install hazard-warning alarms to alert workers of vessel over-pressurization and potential chemical hazards.

CONTROL POINT: Design, Operations, Maintenance

(2) Contaminants (Well Installation).
Description: During well installation, workers may be exposed to contaminants, such as VOCs, dusts, and metals in soil and development water through the inhalation/ingestion/dermal contact routes.

Control: Controls for contaminants include

- Apply water or an amended water solution to the area during well installation to help control the generation of airborne dusts, particulates, and VOCs.

- Use respiratory protection including approved filter/cartridges such as HEPA (N100, R100, P100) filters for particulates, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Analyze work tasks and potential for chemical exposure to determine the correct PPE and/or respirator cartridge(s). The analysis should include a chemical waste profile to help ensure that the PPE specified will be appropriate for the respective chemical hazard(s).

CONTROL POINT: Construction, Operations, Maintenance

(3) Chemical Exposure Via Dual-Phase Extraction.
Description: During operation of a dual-phase extraction system, workers may be exposed to chemical materials, such as hydrogen sulfide, VOCs, and intermediate byproducts.

Control: Controls for chemical exposure include

- Wear respiratory protection to control inhalation exposures based on an analysis of the type of respirator required before issuance.
- Include a chemical profile on the waste materials to ensure that the specified respirator and filter/cartridge will be appropriate.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards

Radioactive Materials.
Description: In some geological settings, workers may be exposed to naturally occurring radon gas. Radon gas and radon progeny do not present a significant external hazard. While radon progeny may present an internal hazard, quantities of radon progeny normally present would not pose a significant exposure hazard.

Control: Controls for radioactive materials include

- Check operation of emission control technologies to limit exposure.
- Consult a qualified health physicist for proper guidance if excessive levels are suspected or encountered.

CONTROL POINT: Design, Operations, Maintenance

d. Biological Hazards.

No unique hazards are identified.

Chapter 10
Air Sparging/Oxygen Enhancement With Air Sparging

10-1. General.

The process of air sparging, its applications, and effectiveness are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

10-2. Technology Description.

a. Air Sparging Methods.

Groundwater air sparging involves the injection of air into groundwater to achieve the following objectives:

- Increased oxygen supply to promote aerobic biodegradation of certain contaminants.
- Removal of volatile organic compounds (VOCs) by physical mechanisms (e.g., desorption and volatilization of compounds directly into the enhanced air stream).

A typical air sparging system consists of specially designed injection wells to inject air into the formation, typically accompanied by a properly designed soil vapor extraction (SVE) system to capture the contaminated off gas. Air is injected into the subsurface under pressure, where it creates an inverted cone of partially aerated soils surrounding the injection point well. The air displaces pore water, volatilizes organics, and exits the saturated zone into the vadose zone. Off gas is then captured by an SVE system installed in the unsaturated zone and treated prior to release. The sparged air also transfers dissolved oxygen into the groundwater, capillary fringe water, and soil moisture in the unsaturated zone.

Nutrients can be injected into the unsaturated zone in water or injected into the saturated zone, dissolved in water slugs, and moved through sparging points or secondary injection wells. Indigenous microbes use injected oxygen and nutrients in enzyme reactions resulting in the transformation and/or destruction of the contaminants. A schematic diagram of an air sparging system is presented in Figure 10-1.

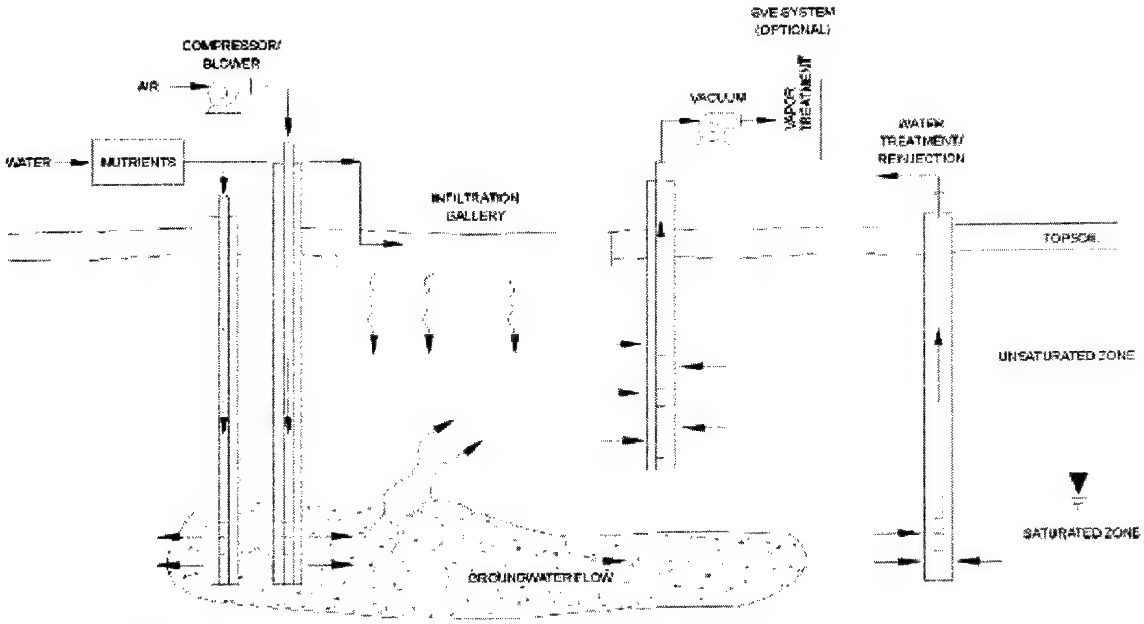


FIGURE 10-1. AIR SPARGING/BIOSPARGING

b. Applications.

Air sparging is effective for removing substantial quantities of volatile hydrocarbons and chlorinated organics in certain geologic settings. Air sparging can be enhanced by the use of oxygen, hydrogen peroxide, or ozone. Oxygen enhancement by the injected air can increase the oxygen content of the groundwater and soil gas, thus aiding bioremediation processes. Additions of ozone in sparging treatments can partially oxidize hard-to-treat organic compounds, such as chlorinated ethylene and complex aromatics, enhancing more traditional treatments by aerobic bioremediation and volatilization.

c. Effectiveness.

The effectiveness of air sparging depends on the geologic characteristics of the site, especially the ease of transmission of air through the soil pore structure. Groundwater air sparging occasionally requires groundwater pump-and-treat systems as well, since sparging effectively creates groundwater mounding around the sparge points, causing radial flow away from the points, and thus the potential to spread groundwater contamination.

10-3. Hazard Analysis.

Principal unique hazards associated with air sparging/oxygen enhancement, methods for control, and control points are described below.

a. Physical Hazards.

(1) Fire and Explosion Hazards (Drilling).
Description: Soil boring using hollow-stemmed augers may cause a fire or explosion during drilling into soils saturated with flammable or combustible materials in unusual or extraordinary conditions. Sparks generated when a metal auger bit strikes against rocks, metal, or other underground objects may ignite a flammable atmosphere inside the bore hole.

Fire or explosion may also result from drilling into soil contaminated with readily flammable/combustible wastes such as carbon disulfide, gasoline, or explosives such as metal fulminates. This hazard is rare.

Control: Controls for fire/explosion hazards include

- Use mud or water rotary drilling methods, which add moisture to the cutting area.
- Fill bore holes to prevent vapor accumulation.
- Have adequate fire fighting equipment always at hand to extinguish any fires generated.
-
- CONTROL POINT: Construction, Maintenance

(2) Utility Contact Hazard.
Description: Fire, explosion, or electrocution hazards may exist when using hollow-stemmed auger drilling methods if the rotating auger contacts and/or ruptures underground utilities such as electrical and gas lines or contacts overhead electric lines.

Control: Controls for utility contact hazards include

- Contact local utilities and public works personnel to determine the locations of all utilities. When there is any doubt or uncertainty, conduct a utility survey, probe with a metal rod prior to excavation, or hand excavate to determine the exact location of utilities prior to drilling. Once utilities are located, careful excavation by backhoe may be allowed.
- Post an observer to the side to guide when raising a drill mast.
- Do not move the drilling rig with the mast raised.

CONTROL POINT: Design, Construction, Maintenance

(3) Fire (Oxygen Enhancement).

Description: Due to the presence of high levels of oxygen in an enhanced air sparge system, there may be an increased risk of starting a fire.

Control: A control for fire due to oxygen enhancement includes

- Inspect oxygen delivery systems regularly for leaks and the elimination of all sources of ignition.

CONTROL POINT: Operations, Maintenance

(4) Fire and Explosion (Flammable Gas).
Description: Fires and explosions may occur due to emissions of flammable VOCs at the surface or in the SVE collection system. Sparks, heat sources, and static electricity may ignite explosive gases, causing rupture of the collection system.

Control: Controls for fire/explosion due to flammable gas include

- Verify that the hazardous area classifications, as defined in NFPA 70-500 1 through 500-10, are indicated on the drawings.
- Use all controls, wiring, and equipment in gas collection that complies with EM 385-1-1, Section 11.G and NFPA 70 for the identified hazard areas.
- Use grounded equipment and/or equipment with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1, Section 11 or NFPA 70 requirements.
- Allow only trained, experienced workers to work on the systems.
- Inspect systems regularly for leaks.
- Control all sources of ignition.
- Ventilate areas adequately to help prevent the accumulation of flammable gases.

CONTROL POINT: Design, Construction, Operations, Maintenance

(5) Equipment Hazards (Drilling).
Description: The rotating drilling auger poses a hazard to workers as loose clothing may become entangled with the revolving auger.

Control: Controls for equipment hazards during drilling include

- Prohibit the use of loose clothing.
- Use low-profile auger pins.
- Use long-handled shovels to remove soil cuttings from the borehole.

CONTROL POINT: Construction, Maintenance

(6) Blower Hazards.
Description: Blowers may be equipped with unguarded pulleys that may cause entanglement of loose clothing.

Control: Controls for blower hazards include

- Use guarded pulleys and guarded moving or rotating mechanical devices on blowers.
- Inform workers that guards must be in place for equipment operation.

CONTROL POINT: Design, Operations, Maintenance

(7) Fire Hazard (Piping Systems).
Description: Piping systems that become plugged may induce failure of the vacuum pump causing an electrical fire. Also pipes or joints may burst from excessive pressure.

Control: A control for fire due to piping systems includes

- Inspect and clean piping systems periodically to help prevent blockage from material buildup.

CONTROL POINT: Design, Operations, Maintenance

(8) Heat Stress.
Description: Workers may be exposed to elevated temperatures due to excessive heating of blowers and other process equipment. The exposure may induce heat stress.

Control: Controls for heat stress include

- Use the correctly sized blowers, motors, and other equipment to prevent overheating.
- Train workers vigorously in the signs and symptoms of heat stress.
- Use the Buddy System and provide easy access to water.

CONTROL POINT: Design, Operations, Maintenance

(9) Steam Pressure Washing.
Description: Steam pressure washing of equipment may expose workers to thermal or burn hazards, eye hazards due to flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control: Controls for steam pressure washing include

- Use insulated gloves (e.g., silica fabric gloves).
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(10) Muscle Injuries.

Description: Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control: Controls for muscle injuries include

- Do not require workers to lift heavy loads manually.
- Use proper lifting techniques including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385-1-1, Section 14.A).
- Use mechanical lifting equipment to lift or to move loads.

CONTROL POINT: Design, Construction, Operations, Maintenance

(11) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Toxic Ozone Exposure.
Description: The use of oxygen or ozone enhancement may create an increased flammability potential or toxic (ozone) exposure.

Control: Controls for toxic (ozone) exposure include

- Ventilate the affected area adequately.
- Inspect piping systems regularly for leaks.
- Monitor for ozone and train workers in ozone hazard recognition including odor identification.

CONTROL POINT: Design, Operations, Maintenance

(2) Contaminants (Well Installation).

Description: During well installation, workers may be exposed to contaminants, such as VOCs, dusts, and metals in soil and development water through the inhalation/ingestion/dermal contact routes.

Control: Controls for contaminants include

- Apply water or an amended water solution to the area during well installation to help control the generation of airborne dusts, particulates, and VOCs.
- Use respiratory protection including approved filter/cartridges such as HEPA (N100, R100, P100) filters for particulates, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Analyze work tasks and potential for chemical exposure to determine the correct PPE and/or respirator cartridge(s). The analysis should include a chemical profile on the waste materials to help ensure the equipment specified will be appropriate for the respective chemical hazard(s).

CONTROL POINT: Construction, Maintenance

(3) Chemical Materials and Byproducts (Operation).
Description: During operation of the system equipment, workers may be exposed to chemical materials, such as hydrogen sulfide, VOCs, carbon dioxide, and intermediate byproducts by the inhalation/ingestion/dermal contact exposure routes.

Control: Controls for chemical exposure include

- Use proper ventilation.
- Wear appropriate PPE (e.g., an air-purifying respirator with organic vapor cartridges; air-purifying respirators for H_2S exposure are for escape only).
- Check closed systems, such as SVE, routinely for leaks with PIDs, air samples, O_2 meters, leak detection fluids, explosive gas meters, or specific gas tests such as Draeger-type tubes. Repair leaks immediately.
- Use vent stack heights that are adequate to disperse off gas.
- Designers: anticipate byproducts and products and make certain that the technology for off-gas treatment (e.g., activated carbon, condensation, catalytic oxidation) is effective and safe.

CONTROL POINT: Design, Operations, Maintenance

(4) Ozone Exposure.
Description: Ozone exposure may occur via the inhalation/dermal contact exposure routes from leaks in equipment used to generate ozone. Ozone is an irritant to skin, eyes and mucous membrane systems.

Control: Controls for ozone exposure include

- Use closed delivery systems for the addition of ozone to help minimize worker exposure.
- Test the equipment used to generate ozone for leaks prior to use.
- Perform regular maintenance and leak tests according to the manufacturer's instructions.
- Train workers in ozone hazard recognition.

CONTROL POINT: Design, Operations, Maintenance

(5) Hydrogen Peroxide Exposure.
Description: During handling of hydrogen peroxide, workers may be exposed to liquid hydrogen peroxide via the inhalation/ingestion/dermal contact exposure routes. Hydrogen peroxide is an irritant to the skin, eyes, and mucous membranes.

Control: Controls for hydrogen peroxide exposure include

- Use closed delivery systems for the addition of hydrogen peroxide to help minimize worker exposure.
- Test the system for leaks prior to use.
- Perform regular maintenance and leak tests according to the manufacturer's instructions.
- Train workers in hydrogen peroxide hazard recognition.

CONTROL POINT: Design, Operations, Maintenance

(6) VOC Migration.
Description: Injection (sparging) wells may cause migration of VOCs into subsurface structures, such as basements and sewers. The VOCs may be toxic and/or flammable, resulting in chemical exposure or the potential for a fire or explosion.

Control: Controls for VOC migration include

- System designer: determine the pressure range of the system and install hazard warning alarms to prevent over-pressurization.
- Perform periodic air testing in basements and other areas where VOCs may migrate to ensure safe levels.

CONTROL POINT: Design, Operations, Maintenance

(7) Confined Space Chemical Hazards.
Description: During entry into confined space, such as a manhole to collect condensate samples, workers may be exposed to airborne chemical hazards if the atmosphere in the confined space contains a toxic chemical or is oxygen deficient.

Control: Controls for confined space chemical hazards include

- Implement a confined-space entry program that includes worker training and air-testing procedures prior to entering confined space (see 29 CFR 1910.146).
- Test all atmospheres of confined space prior to and during entry.
- Ventilate confined spaced if a hazardous atmosphere exists.

CONTROL POINT: Operations

(8) Toxic Intermediate Products.
Description: Biological degradation of certain chlorinated organic compounds may produce toxic intermediate products including vinyl chloride. Vinyl chloride exists as a gas and may accumulate to higher levels in boreholes or in the system. Workers may be exposed to intermediate products during operation or maintenance of the system.

Control: Controls for toxic intermediate products include

- Ventilate the affected area.
- Select the proper respirator according to 29 CFR 1910.1017 or 29 CFR 1910.134 for other intermediate products if exposures are not less than the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL).
- Check with the respirator manufacturer to verify use in atmospheres containing vinyl chloride.
-
- CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

Radon Exposure.
Description: In some geological settings, workers may be exposed to naturally occurring radon gas. The gas is drawn from the soil in the SVE stream. Radon gas and radon progeny do not present a significant external hazard. While breakdown products of radon (progeny) may present an inhalation/ingestion hazard, quantities of radon progeny normally present would not pose a significant exposure hazard.

Control: Controls for radon exposure include

- Check for proper operation of emission control technologies to limit exposure to acceptable levels.
- Consult a qualified health physicist if excessive levels are suspected or encountered.

CONTROL POINT: Design, Operations, Maintenance

d. Biological Hazards.

(1) Biological Contaminants.
Description: At those sites involving medical wastes or sewage sludge, microorganisms in the soil may pose exposure hazards during system installation activities. Workers may be exposed to inhalation/ingestion/dermal contact with pathogens such as *Coccidioides sp., Histoplasma sp.,* and *Mycobacterium sp.* if contaminated dusts become airborne.

Control: Controls for biological contaminants include

- Reduce the generation of airborne microbe-contaminated dust with the periodic application of water, surfactant amended water, or emission-suppressing foams to the active excavation/drilling areas. The addition of foam to control vapors may also create a slip and fall hazard. Workers should not walk on areas where foam has been applied.
- Erect wind screens and use portable surface covers.
- Use the proper types of PPE: an air-purifying respirator with HEPA (N100, R100, P100) filter/cartridge and rubber gloves.
- Use experienced workers, repeated health and safety meetings, decontamination stations, and other standard procedures.

CONTROL POINT: Construction, Maintenance

(2) Pests.
Description: Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus.

Control: Controls for pests include

- Perform periodic inspections of the site to identify stinging insects and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents for exposure control. Workers should check their skin and clothing for ticks periodically.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 11
Landfarming

11-1. General.

The process of landfarming, its requirements, application, and resulting waste streams are discussed in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

11-2. Technology Description.

a. Landfarming Methods.

Landfarming is a biological remediation technology in which contaminants in soils, sediments, sludges, or soil-like materials are degraded by microorganisms to produce innocuous or stabilized byproducts.

During a landfarm operation, soils, sediments, sludges, or soil-like materials are treated in situ, and then are applied to a soil surface or excavated and placed on liners to prevent further contamination (Figure 11-1). Populations of indigenous microorganisms are also stimulated to grow and transform the contaminants. The following parameters are usually monitored or controlled:

- Mixing (tilling).
- Leachate collection system (sand and/or gravel).
- Geomembrane.
- Secondary leachate collection/leak detection layer constructed of sand/gravel.
- Secondary synthetic liner.
- Low permeability compacted clay liner.
- Moisture content (controlled by irrigation or spraying).
- Oxygen level (controlled by tilling the soil or aeration).
- Nutrients (nitrogen and phosphorus are controlled by adding fertilizer, as necessary).
- pH (controlled by adding lime).
- Soil bulking (controlled by blending soil amendments with soil, if necessary).
- Temperature (temperature is usually not controlled, operation is often seasonal).

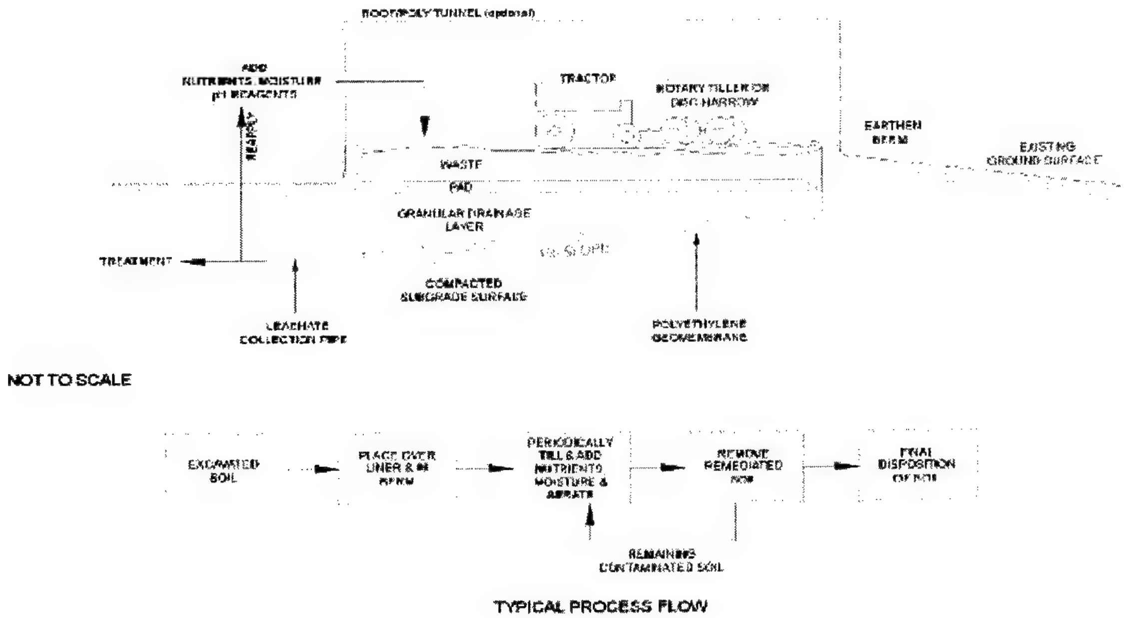


FIGURE 11-1. LANDFARMING

b. Equipment and Land Requirements.

Landfarming utilizes commercially available farm equipment such as tractors, rotary tillers, chisel plows, soaker hoses, and rotary sprinklers. The nature of the technology is such that it requires substantial open areas to create land treatment units, and these areas must be prepared for proper drainage, equipment access, and materials management.

c. Applications.

Landfarms have been most successful in treating petroleum hydrocarbons such as diesel fuel, No. 2 and No. 4 fuel oils, JP-5, oily sludge, wood-preserving wastes (pentachlorophenol, polycyclic aromatic hydrocarbons [PAHs], and creosote), coke wastes, and some pesticides. Landfarm degradation rates decrease with an increase in molecular weight or with an increase in the number of aromatic and/or cyclic rings, (e.g., PAHs). Chlorinated or nitrated compounds are also usually more difficult to degrade than hydrocarbons. Depending on regulatory requirements, treated soil may be backfilled to its original location, left on the land treatment unit, or disposed of off site.

d. Resulting Waste Streams.

Landfarming processes may produce three streams that may require additional handling:

- Wastewater (may require additional treatment).
- Treated soil (or soil-like materials).
- Volatile emissions from soil tilling.

11-3. Hazard Analysis.

Principal unique hazards associated with landfarming, methods for control, and control points are described below.

a. Physical Hazards.

(1) Equipment Hazards.
Description: During soil excavation and landfarm construction, workers may be seriously injured or killed by heavy equipment such as front-end loaders and scrapers. Landfarm construction may include the preparation of berms that may be steep and become slippery in wet or rainy conditions.

Control: Controls for equipment hazards include

- Use heavy equipment with a backup alarm to alert workers.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Do not walk on or near the berms, especially during or after periods of heavy rainfall.

CONTROL POINT: Construction, Operations, Maintenance

(2) Wind.
Description: Installation of landfarm liners/covers in high winds may pose hazards to workers as blowing liners may trip or knock down workers holding or standing on or beside unsecured liners.

Control: Controls for wind include

- Install liners on calm days.
- Place soil or sand bags onto the liner to anchor it. The installer should determine the anchoring needs at the time of installation and ensure that anchoring specifications are met or exceeded.

CONTROL POINT: Construction, Maintenance

(3) Slip Hazards.
Description: Installation of landfarm liners/covers can pose a slip hazard, particularly when wet. Plastic and wet clay liners can be very slippery, especially when placed on the slopes or used for footing.

Control: Controls for slip hazards include

- Use rope ladders for ascending/descending lined slopes.
- Select appropriate shoe soles for maximum traction.
- Erect barriers or warnings around excessively wet areas of liner.
- Lay high-traction walkways over the liners.
- Carry light loads or use more workers to carry larger single loads.

CONTROL POINT: Design, Construction, Operations, Maintenance

(4) Sharp Liner Edges.
Description: Synthetic liners are made in varying thicknesses and rigidities. Some liner edges are sharp and stiff after cutting to shape and can inflict cuts and abrasions to the skin and eyes.

Control: Controls for sharp liners include
- Wear long-sleeved shirts, full-length pants, and appropriate work gloves (e.g., leather or leather-palmed) for better grip and protection.
- Wear safety glasses or goggles to help prevent eye injuries.

CONTROL POINT: Construction, Maintenance

(5) Heat Stress.
Description: Heat-related illnesses may occur during liner installations. Because most synthetic liner materials are dark or black to enhance ultraviolet (UV) resistance, they absorb radiant energy and emit considerable heat. The polished surfaces of liner materials can also reflect considerable angled radiant energy, enhancing the energy absorbed by the worker even when under a canopy or wearing a hat. Heat stress, including heat exhaustion and heat stroke, may occur to workers during operations and conditions that contribute to the heat load. Hot and humid conditions combined with operations, such as liner welding or other heat-producing activities, may further increase the potential for heat-related illnesses.

Control: Controls for heat stress include
- Train workers vigorously in the signs and symptoms of heat stress.
- Use the Buddy System.
- Provide easy access to water, frequent mandatory breaks, and canopies or other shaded break areas.
- Require the use of sun hats and other protective clothing.

CONTROL POINT: Design, Construction, Operations, Maintenance

(6) Muscle Injuries.
Description: Manual lifting and moving of large rolls of liner material or weighted anchoring materials may expose workers to lower back and shoulder stress.

Control: A control for muscle strain includes

- Use mechanical lifting equipment, such as cranes, backhoes with cables, and spreaders to lift and move liner material.

CONTROL POINT: Construction, Operations, Maintenance

(7) Burn Hazards.
Description: Burn hazards to the skin may exist with different types of operating equipment including a liner extrusion welder and generators.

Control: Controls for burn hazards include
- Make sure all personnel using or exposed to hot operating equipment during liner installation know equipment hazards.
- Guard all exposed, heated surfaces to prevent accidental contact.
- Prepare procedures for the safe operation, repair, and maintenance of equipment and include a testing procedure for determining safe temperature.
- Use insulated gloves with gauntlets, coveralls, and face protection if necessary.

CONTROL POINT: Construction, Maintenance

(8) Moving Equipment Hazards.
Description: Landfarm units may require periodic aeration by mechanically turning over soils with heavy equipment such as mixing equipment, rototillers, plows, discs, and tillers. Other devices, such as a "scarab"-type device may throw debris during the turning process. Pre-screening or sizing equipment, such as grinders, shakers, and screeners may pose hazards if unguarded. Appendages or loose clothing may become entangled in pulleys, drive shafts, and other moving equipment.

Control: Controls for moving equipment include
- Keep clear of operating equipment and approach only when within view of the operator.
- Guard all moving or rotating equipment to prevent accidental contact.
- Operate the system with the machine guards in place.
- Prohibit the use of loose clothing around equipment.

CONTROL POINT: Construction, Operations, Maintenance

(9) Puncture Hazards.
Description: Workers may be exposed to puncture and cut hazards to feet and hands from rough or jagged waste materials during landfarming operations.

Control: Controls for puncture hazards include
- Wear safety boots with steel shanks to prevent cuts.
- Minimize manual handling of waste material.

- Wear cut-resistant gloves if contact with waste materials is necessary.

CONTROL POINT: Construction, Operations, Maintenance

(10) Trip Hazards.
Description: Trip hazards may exist with hoses and piping systems used for irrigation of the landfarm.

Control: Controls for trip hazards include

- Exercise caution when walking over hoses and pipes.
- Use extra lighting if necessary to ensure adequately illuminated walkways.

CONTROL POINT: Design, Maintenance

(11) Respirable Quartz Hazard.
Description: Depending on soil types, exposure to respirable quartz may be a hazard. Consult geologists to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422, followed by analysis of the fines by X-ray diffraction to determine fine material quartz content.

Control: Controls for respirable quartz include

- Wet the soil periodically with water or amended water to minimize worker exposure.
- Use respiratory protection, such as an air-purifying respirator equipped with a HEPA (R100, N100, P100) filter/cartridge.

CONTROL POINT: Construction, Operations

(12) Electrocution.
Description: Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control: Controls for electrocution include

- Locate overhead power lines, either existing or proposed, in the pre-design phase.
- Keep all lifting equipment, such as cranes, forklifts, and drilling rigs at least 10 feet from a power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.E.

CONTROL POINT: Design, Construction, Operations

(13) Equipment Hazards (Slopes).
Description: Equipment used to move soil and liner materials on steep slopes may roll over, seriously injuring or killing the operator.

Control: Controls for equipment use on slopes include

- Design the angle of the slope to minimize the potential for roll-over.
- Maintain safe operating conditions for equipment during construction.
- Use equipment with roll-over protective devices (ROPS).
- Do not operate equipment on excessively steep slopes or unstable ground.
- Wear seat belts during operation.

CONTROL POINT: Design, Construction, Operations

(14) Traffic Hazards.
Description: During the implementation of field activities, equipment and workers may come in close proximity to traffic. Equipment may also need to cross public roads. The general public may be exposed to traffic hazards during loading and transporting soil.

Control: Controls for traffic hazards include

- Post warning signs according to the criteria of the Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways.
- Develop a traffic management plan before remediation activities commence to help prevent accidents involving site equipment. EM 385-1-1, Section 21.I10 provides plan details.

CONTROL POINT: Design, Construction, Operations

(15) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards

(1) Vapors and Solvent Hazards.
Description: The heating or cementing of the cover/liner materials may generate vapors, either from the cement applied or from thermal decomposition, and/or outgassing of the liner material components such as

plasticizers (e.g., phthalate esters, adipate esters), or from the solvents contained in the cementing agent (e.g., methyl ethyl ketone, methylene chloride). A vapor inhalation hazard may exist to workers during liner installation. A dermal hazard may also exist from skin contact with the cementing chemicals and/or waste materials generated during installation.

Control: Controls for hazardous vapors and solvents include

- Ventilate the area or use appropriate respirators to control exposures during installation.
- Select respirator cartridges (e.g., organic vapor cartridges) based on consultations with the liner manufacturer(s) and the potential compounds that may be emitted.
- Use personal protective equipment (PPE) such as chemically-resistant gloves (e.g., nitrile for gasoline) to help control dermal exposure.
- Analyze work tasks and potential for chemical exposure to determine the correct PPE and/or respirator cartridge(s) if necessary. The analysis should include a chemical profile on the liner and/or cementing agents to ensure appropriate equipment.

CONTROL POINT: Construction, Maintenance

(2) Contaminants.
Description: Workers may be exposed to contaminants of concern and chemical reagents. The addition of urea or other ammonia-based fertilizers may result in worker exposure to ammonia. Intermediate degradation products, resulting from breakdown of contaminants of concern, may also represent exposure hazards. Exposure may occur via inhalation/ingestion/dermal contact routes of exposure during loading, unloading, preprocessing, tilling, turning, and other landfarming processes where soils are agitated.

Control: Controls for chemical contaminants include

- Use PPE (e.g., butyl rubber gloves for exposure to nitrogen compounds) to control dermal exposure during urea and nitrogenous fertilizer additions.
- Analyze work tasks and potential for chemical exposure to determine the correct PPE and/or respirator cartridge(s), if needed. The analysis should include obtaining specific chemical hazard information to ensure appropriate PPE.
- Use respiratory protection including the use of an air-purifying respirator equipped with HEPA (N100, R100, P100) filters and organic vapor cartridges.

CONTROL POINT: Operations

(3) Enclosed Land Treatment Facilities.
Description: If the land treatment unit facilities are enclosed or tented, workers entering the landfarm may be entering a confined space and require respiratory protection.

Control: Controls for enclosed treatment facilities include

- Test the atmosphere within the enclosure or tent frequently to ensure a safe atmosphere.
- Develop and implement a confined-space entry program if the testing indicates atmospheric contaminants or oxygen depletion (see 29 CFR 1910.146).

CONTROL POINT: Design, Operations

(4) Acidic or Caustic Hazards.
Description: Workers may be exposed to burn hazards during handling of acidic or caustic chemicals potentially used for pH control. Some materials used in landfarming may pose explosion hazards if contact is made with other incompatible materials (e.g., ammonium nitrate and fuels). Others may be hygroscopic, which may result in chemical reactions.

Control: Controls for acidic or caustic chemicals include

- Minimize contact with acidic or corrosive chemical materials by using mechanical chemical delivery methods.
- Wear gloves (e.g., nitrile) and other PPE that is resistant to the materials handled including eye and face protection.
- Segregate chemical reagents used in landfarming to prevent accidental mixing of reactive chemicals, especially ammonium nitrate fertilizers and fuels.

CONTROL POINT: Design, Operations

c. Radiological Hazards.

No unique hazards are identified.

d. Biological Hazards.

(1) Pathogenic Microbes.
Description: Landfarm activities may expose workers via inhalation/ingestion/dermal contact exposure routes to pathogenic microbes if the wastes being treated contain pathogenic agents. The hazard may increase during dry and windy periods when microbe-entrained dusts may become airborne from soil agitation, aerators, or wind. Exposure may occur during installation of the landfarm liner or during agitation of the waste material. Inhalation of pathogenic microbes may cause allergic reactions or illness.

Control: Controls for pathogenic microbes include

- Apply water periodically to limit airborne dust and exposure.
- Use PPE such as rubber gloves to help prevent dermal exposure to microorganisms.

- Use respiratory protection such as an air-purifying respirator with HEPA (N100, R100, P100) filters during dusty periods.

CONTROL POINT: Construction, Operations

(2) Pests.
Description: Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus.

Control: Controls for pests include

- Perform periodic inspections of the site to identify bee hives and wasp nests and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents for exposure control. Workers should check their skin and clothing for ticks periodically.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 12
Composting

12-1. General.

The methods of composting, equipment requirements, applications, and resulting waste streams are discussed in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

12-2. Technology Description.

a. Composting Methods.

Composting is a biological remediation technology in which contaminants in soils, sediments, sludges, or soil-like materials are biodegraded and/or transformed to produce innocuous or stabilized byproducts.

During a composting operation, soils, sediments, sludges, or soil-like materials are treated ex situ in piles or windrows (Figure 12-1). Populations of indigenous microorganisms are stimulated to grow and transform the contaminants. The following parameters are usually monitored or controlled:

- Mixing (tilling).
- Moisture content (controlled by irrigation or spraying).
- Oxygen level (controlled by tilling or aeration).
- Nutrients (nitrogen and phosphorus are provided by adding organic amendments).
- pH (soil and amendments usually provide sufficient buffering capacity).
- Soil bulking (controlled by blending organic amendments with soil).
- Temperature (proper mixing, moisture, and amendment selection is required to maintain thermophilic conditions).

Composting is a biological remediation process in which soils, sediments, sludges, or soil-like materials are mixed with organic amendments such as wood chips, manure, hay, and vegetable (e.g., potato) wastes. The process generates elevated temperatures (in the range of 43° to 65° C) from heat produced by microbial activity. Maximum degradation is achieved by maintaining thermophilic conditions for an extended period of time. Three different approaches to composting can be utilized:

- Compost is formed into piles and aerated with blowers or vacuum pumps (aerated static pile composting).
- Compost is placed in a reactor vessel where it is mixed and aerated (mechanically agitated in-vessel composting).
- Compost is placed in long piles (windrows) and periodically mixed with mobile equipment (windrow composting). Windrow composting is generally thought to be the most cost-effective form of composting.

After completion of the composting process, the treated material is typically placed in designated locations on the site, in accordance with regulatory requirements.

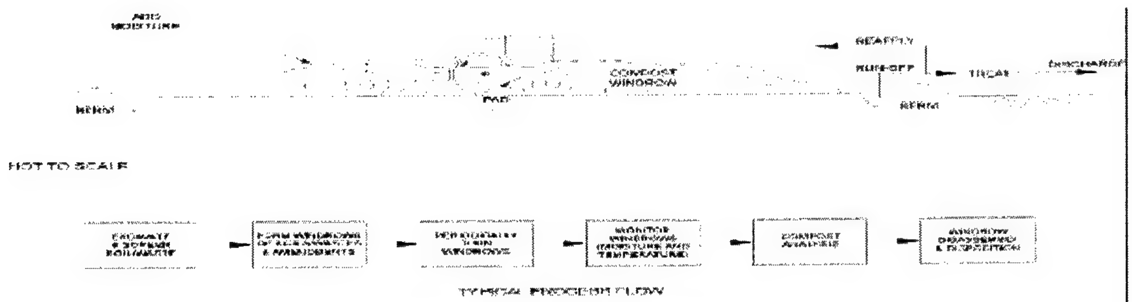


FIGURE 12-1. COMPOSTING

b. Equipment Requirements.

Composting techniques may utilize commercially available farm equipment such as tractors, rotary tillers, and irrigation devices. Composting requires substantial space and will result in a volumetric increase in material due to the addition of the amendments. For hazardous waste applications, specialized implements are usually required to turn the compost.

c. Applications.

Aerobic, thermophilic composting has been shown to be effective for the remediation of explosives (TNT, RDX, and HMX), PAHs, and some pesticides. Although some solution may occur, heavy metals and most other inorganic contaminants are not treated by composting.

d. Resulting Waste Streams.

Composting processes may produce three streams that may require additional handling:

- Wastewater (may require additional treatment).
- Treated soil (or soil-like materials).
- Volatile emissions.

12.3 Hazard Analysis.

Principal unique hazards associated with composting, methods for control, and control points are described below.

a. Physical Hazards.

(1) Equipment Hazards.
Description: During soil excavation and compost pile construction, workers may be seriously injured or killed by heavy equipment such as front-end loaders and scrapers. Construction may include the preparation of berms that may be steep and become slippery in wet or rainy conditions.

Control: Controls for equipment hazards include

- Use heavy equipment with a backup alarm to alert workers.
- Approach operating equipment from the front and within view of the operator, preferably making eye contact.
- Do not walk on or near the berms, especially during or after periods of heavy rainfall.

CONTROL POINT: Construction, Operations, Maintenance

(2) Moving Equipment Hazards.
Description: Windrows require periodic aeration using specialized equipment for turning the compost. Other devices, such as a scarab-type device may throw debris during the turning process. Pre-screening or sizing equipment, such as grinders, shakers, and screeners may pose hazards if unguarded. Appendages or loose clothing may become entangled in pulleys, drive shafts, and other moving equipment.

Control: Controls for moving equipment include

- Keep clear of operating equipment and approach only when within view of the operator.
- Guard all moving or rotating equipment to prevent accidental contact.
- Operate the system with the machine guards in place.

- Prohibit the use of loose clothing around the equipment.

CONTROL POINT: Construction, Operations, Maintenance

(3) Puncture Hazards.
Description: Workers may be exposed to puncture and cut hazards to feet and hands from rough or jagged waste materials during composting operations.

Control: Controls for puncture hazards include
- Wear safety boots with steel shanks to prevent cuts.
- Minimize manual handling of waste material.
- Wear cut-resistant gloves if contact with waste materials is necessary.

CONTROL POINT: Construction, Operations, Maintenance

(4) Trip Hazards.
Description: Trip hazards may exist with hoses and piping systems used for irrigation of the composting unit.

Control: Controls for trip hazards include
- Exercise caution when walking over hoses and pipes.
- Use extra lighting if necessary to ensure adequately illuminated walkways.

CONTROL POINT: Design, Maintenance

(5) Fire Hazards.
Description: Fire hazards may exist with composting as elevated temperatures and drying may increase the potential for spontaneous combustion.

Control: Controls for fire hazards include
- Mix composting material periodically and maintain the proper water content to control compost temperature and prevent fires.
- Reduce the dimensions of the compost windrows (and the piles of compost) to prevent temperatures from exceeding desired levels.

CONTROL POINT: Design, Operations

(6) Respirable Quartz Hazard.
Description: Depending on soil types, exposure to respirable quartz may be a hazard. Consult geologists to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422, followed by analysis of the fines by X-ray diffraction to determine fine material quartz content.

Control: Controls for respirable quartz include
- Wet the soil periodically with water or amended water to minimize worker exposure.

- Use respiratory protection, such as an air-purifying respirator equipped with a HEPA (N100, R100, P100) filter.

CONTROL POINT: Construction, Operations

(7) Electrocution.
Description: Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control: Controls for electrocution include
- Locate overhead power lines, either existing or proposed, in the pre-design phase.
- Keep all lifting equipment, such as cranes, forklifts, and drilling rigs at least 10 feet from a power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.E.

CONTROL POINT: Design, Construction, Operations

(8) Equipment Hazards (Slopes).
Description: The heavy equipment (small and large) used to move compost, soil, and liner materials on steep slopes may roll over, seriously injuring or killing the operator.

Control: Controls for equipment use on slopes include
- Design the angle of the slope to minimize the potential for roll-over.
- Maintain safe operating conditions for equipment during construction.
- Use heavy equipment with roll-over protective devices (ROPS).
- Do not operate equipment on excessively steep slopes or unstable ground.
- Require the use of seat belts.

CONTROL POINT: Design, Construction, Operations

(9) Traffic Hazards.
Description: During the implementation of field activities, equipment and workers may come in close proximity to traffic. Equipment may also need to cross or use public roads. The general public may be exposed to traffic hazards during loading and transporting soil.

Control: Controls for traffic hazards include
- Post warning signs according to the criteria of the Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways.
- Develop a traffic management plan before remediation activities begin to help prevent accidents involving site equipment. EM 385-1-1, Section 21.I10 provides plan details.

CONTROL POINT: Design, Construction, Operations

(10) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Contaminants.
Description: Workers may be exposed to contaminants of concern and degradation products of contaminants. Exposure may occur via inhalation/ingestion/dermal contact routes of exposure during loading, unloading, preprocessing, tilling, turning, and other operations where soils are agitated.

Control: Controls for chemical contaminants include

- Analyze work tasks and potential for chemical exposure to determine the correct personal protective equipment (PPE) and/or respirator cartridge(s), if needed. The analysis should include obtaining specific chemical hazard information to ensure appropriate PPE.
- Use respiratory protection including the use of an air-purifying respirator equipped with HEPA (N100, R100, P100) filters and organic vapor cartridges.

CONTROL POINT: Operations

(2) Enclosed Facilities.
Description: If composting facilities are enclosed or tented, workers may be entering a confined space and require respiratory protection. Elevated levels of CO_2 may accumulate during composting. It is also typical for some ammonia gas to be generated during composting. Exposure to ammonia vapors may occur, especially during windrow turning operations. Although aerobic conditions should be maintained in the compost, if anaerobic conditions are allowed to develop, methane and hydrogen sulfide may be generated.

Control: Controls for enclosed facilities include

- Test the enclosed atmosphere prior to each entry to ensure safety.
- Develop and implement a confined-space entry program if the testing indicates atmospheric contaminants or oxygen depletion (see 29 CFR 1910.146).

CONTROL POINT: Design, Operations

(3) Explosion Hazards.
Description: Some materials used in composting may be explosive, especially when in contact with other incompatible materials (e.g., ammonium nitrate and fuels). Others may be hygroscopic, which may result in chemical reactions.

Control: Controls for explosive hazards include

- Minimize contact with acidic or corrosive chemical materials by using mechanical chemical delivery methods.
- Wear gloves (e.g., nitrile) and other PPE that is resistant to the materials handled.
- Segregate chemical reagents used in composting to prevent accidental mixing of reactive chemicals, especially ammonium nitrate fertilizers and fuels.

CONTROL POINT: Design, Operations

c. Radiological Hazards.

No unique hazards are identified.

d. Biological Hazards.

(1) Pathogenic Microbes.
Description: Composting activities may expose workers via inhalation/ingestion/dermal contact exposure routes to pathogenic microbes. The hazard may increase during dry and windy periods when microbe-entrained dusts may become airborne from soil agitation, aerators, or wind. Exposure may occur during agitation of the waste material. It is possible for pathogens to be present in compost amendments (e.g., bird manure has been implicated as a source of histoplasmosis). Exposure to mold spores, including *Aspergillus fumigates*, may occur during composting operations. Inhalation of pathogenic microbes may cause allergic reactions or illness.

Control: Controls for pathogenic microbes include

- Apply water periodically to limit airborne dust and exposure.
- Use PPE, such as rubber gloves, to help prevent dermal exposure to microorganisms.
- Use respiratory protection such as an air-purifying respirator with HEPA (N100, R100, P100) filter during dusty periods.

CONTROL POINT: Construction, Operations

(2) Snakes and Harmful Animals.
Description: Snakes and other potentially harmful animals are attracted to the higher temperatures associated with composting operations.

Control: Controls for snakes and other animals include
- Inform workers of the potential for snakes and other animals around the compost facility, especially during cooler periods.
- Use loud noises, such as talking and stamping or scuffing feet, to alert animals to the presence of workers in the area.

CONTROL POINT: Operations, Maintenance

(3) Pests.
Description: Workers may be exposed to a wide array of biological hazards, including snakes, bees, wasps, massive fly hatches, ticks, hornets, and rodents during any phase of remediation. The symptoms of exposure vary from mild irritation to anaphylactic shock and death. Deer ticks may cause Lyme disease. Rodents can transmit Hanta virus.

Control: Controls for pests include
- Perform periodic inspections of the site to identify stinging insect nests and to check for snakes and rodents.
- Use professional exterminating companies if necessary.
- Use tick and insect repellents for exposure control. Workers should check their skin and clothing for ticks periodically.

CONTROL POINT: Construction, Operations, Maintenance

Chapter 13
Bioreactors

13-1. General.

Bioreactor methods, applications, and resulting waste streams are discussed in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

13-2. Technology Description.

Bioreactors are contained systems (tanks or ponds) used to degrade contaminants in aqueous solution utilizing suspended or attached microbial systems. Contaminated soil or sludges may be slurried and then fed into bioreactors for treatment.

a. Suspended Growth Systems.

Suspended growth systems include continuous flow, activated sludge processes, or batch reactors. In these systems, contaminated material is circulated in an aeration basin where microbes aerobically or anaerobically degrade organic matter, and ideally produce CO_2, H_2O, methane, and new cells. The cells form a sludge, which is settled out in a clarifier (Figure 13-1). Sludge is then recycled into the aeration basin to maintain acclimated microorganisms and/or sent for disposal.

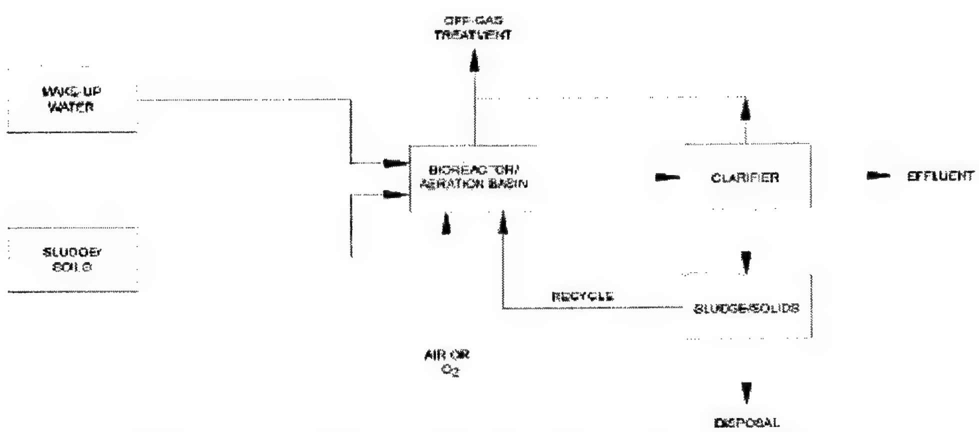


FIGURE 13-1. TYPICAL PROCESS FLOW FOR BIOREACTORS (SUSPENDED GROWTH SYSTEMS)

The levels of contaminants in groundwater usually are not high enough to use suspended growth bioreactors. However, more concentrated waste streams, such as landfill leachate, may be suitable to treatment via suspended growth reactors.

b. Attached Growth Systems.

Attached growth systems (Figure 13-2) include upflow fixed film bioreactors, fluidized bed reactors, rotating biological contactors (RBCs), and trickling filters. In these systems, microbes grow attached to a support matrix. Liquid waste is circulated through the attached growth system where contaminants are removed and degraded by the microbes. "Clean" water is further processed in a clarifier, where sludge is settled and water that meets effluent criteria is discharged. Attached growth systems include the use of active supports (such as activated carbon) that adsorb the contaminant and slowly release it to the microbial population for degradation. Active supports also include wetland ecosystems and column reactors.

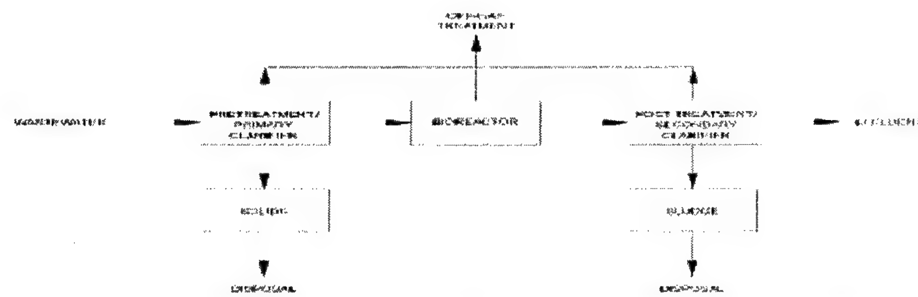


FIGURE 13-2. TYPICAL PROCESS FLOW FOR BIOREACTORS (ATTACHED GROWTH SYSTEMS)

c. Applications.

Bioreactors are used primarily to treat semi-volatile compounds, petroleum hydrocarbons, and halogenated compounds such as chlorobenzene, dichlorobenzene isomers, and some pesticides. Due to the limitations of mixing equipment, the solids content in slurry reactors is usually not more than 20 percent, by weight.

d. Resulting Waste Streams.

Bioreactors produce four streams that may require additional handling:

- Emissions from equalization tank or other pretreatment operations (may require additional treatment).
- Emissions from bioreactor (may require treatment).
- Effluent water from waste treatment.
- Sludge (may require additional treatment prior to disposal)
-

13-3. Hazard Analysis.

Principal unique hazards associated with bioreactors, methods for control, and control points are described below.

a. Physical Hazards.

(1) Fire or Explosion Hazards.
Description: Storage of methanol or other additives or supplements may cause fire or explosion if these materials are spilled and allowed to mingle with incompatible chemicals or are ignited by a potential source of ignition.

Control: Controls for fire or explosion hazards include

- Meet mandatory storage requirements of 29 CFR 1910.106, Flammable and Combustible Liquids.
- Follow appropriate fire and electrical codes.
- Verify that drawings indicate hazardous area classifications, as defined in NFPA 70-500-1 through 500-10.
- Use controls, wiring, and equipment near the tanks that conform to the requirements of EM 385-1-1, Section 11.G and NFPA 70.
- Use grounded equipment and/or equipment with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1, Section 11 or NFPA 70 requirements.
- Permit only trained, experienced workers to work around the storage areas.
- Direct tank vents to prevent contact with sources of ignition.
- Make fire extinguishers rated for energized electrical systems readily available where electrical equipment is installed and operated.

CONTROL POINT: Design, Construction, Operations, Maintenance

(2) Confined Spaces.
Description: Because bioreactors typically generate carbon dioxide gas as a byproduct, workers entering tanks or clarifiers may be exposed to confined spaces with oxygen-deficient atmospheres.

Control: Controls for confined-space entry include

- Test atmospheres in confined spaces prior to entry and follow applicable Occupational Safety and Health Administration (OSHA) standard 29 CFR 1910.146 requirements.
- Design air-handling systems to minimize or eliminate oxygen-deficient locations.

CONTROL POINT: Design, Operations, Maintenance

(3) Electrocution.
Description: If permanent and temporary electrical equipment that is not ground-fault protected contacts water or other liquids, an electrocution hazard exists.

Control: Controls for electrocution include

- Verify that drawings indicate the hazardous area classifications as defined in NFPA 70-500-1 through 500-10.
- Use all controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11.G and NFPA 70 for the identified hazard areas.
- Provide ground fault protection where required by EM 385-1-1, Section 11 or NFPA 70 requirements.
- Permit only trained, experienced workers in equipment areas.

CONTROL POINT: Design, Construction, Maintenance

(4) Unguarded Equipment.
Description: Blowers may be equipped with unguarded pulleys that may cause cuts or entanglement of loose clothing. Floating aerators may be equipped with unguarded propeller blades.

Control: Controls for unguarded equipment include

- Use pulleys and other moving or rotating mechanical devices with guards and operate with guarding in place.
- Design and install emergency shut-off systems if there is a threat of workers falling into actively aerated tanks or ponds with bladed aerators.
- Establish lock-out procedures for shutting down aerators prior to operations on a pond or tank water surface.
- Equip tanks with guardrails, grab rails, and ladders where practical.
- Prohibit the use of loose clothing around the equipment.

CONTROL POINT: Design, Operations, Maintenance

(5) Treatment Buildings.
Description: Permanent or semi-permanent treatment buildings may present life safety hazards such as inadequate egress, fire suppression systems, and/or emergency lighting systems.

Control: Controls for treatment buildings include

- Meet the following construction requirements for permanent and semi-permanent treatment system buildings: ANSI 58.1: Minimum Design Loads for Buildings and Other Structures; the National Fire Code; the National Standard Plumbing Code; Life Safety Code; and the Uniform Building Code.
- Comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations, or local building codes on Superfund, BRAC, or FUDS project sites.

CONTROL POINT: Design, Operations

(6) Fire Hazard (Oxygen-Enriched Atmospheres).
Description: If pure oxygen is being used for aeration, workers may be at an increased risk of spreading a fire due to an oxygen-enriched atmosphere. Usually air, rather than pure oxygen, is used for aeration.

Control: Controls for fire hazards include

- Design and construct oxygen systems according to NFPA 50 Bulk Oxygen Systems at Consumer Sites.
- Provide oxygen systems with safety relief devices in accordance with CGA S-1.3 Safety Relief Devices for Compressed Gas Storage Containers.
- Inspect oxygen delivery systems regularly for leaks.
- Eliminate all sources of ignition during application of oxygen.

CONTROL POINT: Operations, Maintenance

(7) Emergency Wash Equipment.
Description: Emergency shower/eye wash equipment required per 29 CFR 1910.151 are not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing/use.

Control: A control for emergency wash equipment includes

- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping hazards.

CONTROL POINT: Design

(8) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Waste Contaminants and Additives.
Description: Workers may be exposed to waste contaminants by inhalation, ingestion, or absorption. Biological activity of the bioreactors may be enhanced with the addition of nutrients or other chemical agents. These agents may include nutrients, methanol, or other chemicals for pH adjustment (e.g., acids and bases). Workers may be exposed to these chemicals during their application either as a powder or in a liquid state. Acute overexposure symptoms may include irritation of the eyes, skin, and respiratory tracts.

Control: Controls for waste contaminants and additives include

- Use personal protective equipment (PPE) during the application process. PPE requirements may include air-purifying respirators with approved filter/cartridges such as HEPA (N100, R100, P100) filters for particulates, OV cartridges for vapors, or combination filter/cartridges for dual protection, chemically-resistant rubber gloves (e.g., nitrile for gasoline), splash goggles, and aprons.
- Design mechanical addition systems to minimize exposure.

CONTROL POINT: Design, Operations, Maintenance

(2) Toxic Intermediate Products.
Description: Biological degradation of certain organic compounds may produce toxic intermediate products. Degradation of trichloroethylene (TCE) can produce dichloroethylene (DCE) and vinyl chloride (VC). Vinyl chloride exists as a gas and may accumulate to higher levels in collection system boreholes or in the treatment system. Workers may be exposed to intermediate products during operation or maintenance of the system. Anaerobic processes can produce toxic and/or explosive products such as methane or hydrogen sulfide, particularly in confined space areas. Workers may also be exposed to VOCs released from aeration tanks.

Control: Controls for toxic intermediate products include

- Remediation designers: understand and anticipate the generation and management of general and specific process products such as carbon dioxide(CO_2), hydrogen sulfide (H_2S), or vinyl chloride (VC) and design for their management.

- Ventilate the affected area.
- Use air-supplied respiratory protection if required (air-purifying respirators are not recommended for vinyl chloride).
- Cover aeration tanks to prevent the release of VOCs into the work environment.
- Monitor the dissolved oxygen level within aerobic bioreactors to determine if aerobic conditions are being maintained.
- Check periodically for the presence of hydrogen sulfide or to install automated alarms if necessary.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

Radioactive Materials.
Description: Radiological materials may have been buried or naturally occurring radioactive material (NORM) may be present in soils, sludge, or groundwater. Some radioactive materials may present an external hazard. All radioactive materials may present an internal exposure hazard through inhalation or ingestion, although this may be a rare hazard.

Control: Controls for radioactive materials include
- Test the soil, sludge, or groundwater to determine if radioactive materials are present.
- Consult a qualified health physicist to determine the exposure potential and any necessary engineered controls or PPE required.

CONTROL POINT: Design, Operations

d. Biological Hazards.

(1) Pathogenic Microbes.
Description: Bioreactors may expose workers to pathogenic microbes during operation and maintenance. However, exposure to pathogens is usually not a significant concern unless the wastes being fed into the reactors contain pathogenic agents. If the bioreactors are equipped with open aerators, microbe-entrained mists may become airborne. Inhalation of pathogenic microbes may cause allergic reactions or illness. During sludge handling activities, workers' hands may be exposed to microbes and result in accidental ingestion of pathogenic material.

Control: Controls for pathogenic microbes include
- Install aerators that minimize generation of mists and/or install partitions or barriers to contain the mist.
- Minimize skin exposure through the use of PPE, such as chemically resistant

- gloves (e.g., nitrile), splash aprons, face shields, or respirators equipped with HEPA (N100, R100, P100) filters.

CONTROL POINT: Design, Operations, Maintenance

(2) Sludge Contaminants.
Description: Biological sludge after drying may become airborne and thus accidentally inhaled or ingested.

Control: Controls for sludge contaminants include

- Disinfect sludge through pasteurization or long-term storage if necessary. Maintaining sludge in a damp condition will minimize free dust; however, sludge is often dewatered prior to disposal. (Sludge drying beds are the most widely used method of dewatering sludges from municipal wastewater in the United States. Pathogens are usually a much greater concern for municipal wastewater applications than for hazardous waste applications.)
- Use appropriate PPE such as an air-purifying respirator with HEPA (N100, R100, P100) filters when handling sludge in dusty conditions.

CONTROL POINT: Operations, Maintenance

Chapter 14
Biofiltration (Vapor)

14.1 General.

The process of biofiltration and its applications are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

14-2. Technology Description.

a. Process.

Biofiltration uses biodegradation to treat air stream contaminants (volatile organic compounds [VOCs]) prior to releasing the stream to the atmosphere. It can be viewed as a self-renewing adsorption bed. The VOC-laden vapor is passed over a porous bed of high surface area packing that serves both as a support surface for the appropriate microbes and as an adsorbent surface for the VOC. This increases the retention time of the VOC in the bed and permits the microbes more time to degrade organic compounds. The air contaminants are solubilized and in turn are degraded by the microbes. Materials that can serve as packing include sand, activated carbon, ceramic supports, peat moss, wood chips, and glass and plastic beads. As this is a destructive process, the unit operating cost is usually less than adsorbent regeneration processes such as activated carbon. Nutrients and water may be added by spraying across the top surface of the bed. If water is not added, the entering air stream must be humidified to prevent the bed from drying out (which will inhibit microbial activity). Specifically cultured organisms may be used in an effort to shorten the acclimation time at the start of operations. The biofiltration process is illustrated in Figure 14-1.

b. Applications.

The technology is best suited to steady-flow streams where the VOC composition and concentration changes slowly if at all. The bed will generally not keep the exhaust air stream in compliance during periods of shock loading since the microbes require time to grow and adapt to different concentrations of substrate.

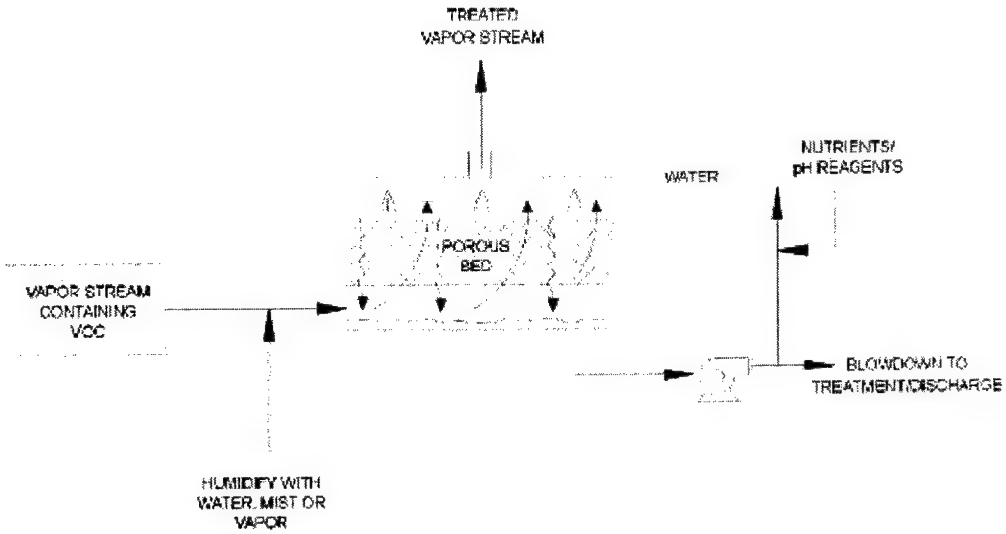


FIGURE 14-1. TYPICAL PROCESS FLOW FOR BIOFILTRATION (VAPOR)

Vapor biofiltration has been successfully used for odor control in the food industry (bakeries and breweries), for solvent vapor treatment from fiber glassing and painting operations, and for the treatment of SVE exhaust streams prior to atmospheric release.

14-3. Hazard Analysis.

Principal unique hazards associated with vapor biofiltration, methods for control, and control points are described below.

a. Physical Hazards.

(1) Confined Space.
Description: Entering process vessels and tanks for activities such as inspection, repair, and maintenance is a confined-space entry. Associated hazards include asphyxiation from the lack of oxygen, overexposure to toxic wastes and byproducts, and engulfment/entrapment by the filtration media.

Control: Controls for confined-space entry include:

- Use confined-space entry procedures for any entry activities (see 29 CFR 1910.146).
- Wear appropriate personal protective equipment (PPE), including respiratory protection (e.g., an air-purifying respirator with organic vapor cartridges) or supplied air, as needed.

- Use the Buddy System for such operations.

CONTROL POINT: Operations, Maintenance

(2) Electrocution.
Description: Workers may be exposed to electrical hazards when working around biofilters. If permanent and temporary electrical equipment that is not ground-fault protected contacts water or other liquids, an electrocution hazard exists.

Control: Controls for electrocution include
- Verify that drawings indicate the hazardous area classifications as defined in NFPA 70-500-1 through 500-10.
- Use controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11.G and NFPA 70 for the identified hazard areas.
- Use grounded or GFIC-protected equipment if required by EM 385-1-1, Section 11 or NFPA 70 requirements.
- Permit only trained, experienced workers in equipment areas.

CONTROL POINT: Design, Construction, Operations, Maintenance

(3) Treatment Buildings.
Description: Permanent or semi-permanent treatment buildings may present life safety hazards such as inadequate egress, fire suppression systems, and/or emergency lighting systems.

Control: Controls for treatment buildings include
- Meet the following construction requirements for permanent and semi-permanent treatment system buildings: ANSI 58.1: Minimum Design Loads for Buildings and Other Structures; the National Fire Code; the National Standard Plumbing Code; Life Safety Code; and the Uniform Building Code.
- Comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations, or local building codes on Superfund, BRAC, or FUDS project sites.

CONTROL POINT: Design, Operations

(4) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Additives.
Description: Biological activity of the biofilters may be enhanced with the addition of nutrients or other chemical agents. These agents may include nutrients (e.g., ammonia nitrate, urea) or other chemicals (e.g., hydrochloric acid, sodium bicarbonate). Workers may be exposed to these chemicals during their application. Acute overexposure symptoms may include eye, skin, and respiratory tract irritation.

Control: Controls for additives include

- Consult chemical manufacturers' Material Safety Data Sheets (MSDS) for potential hazard information and controls including appropriate PPE and train workers accordingly.
- Use recommended PPE (e.g., an air-purifying respirator with organic vapor cartridges) during the application or blending processes.
- Design mechanical addition systems to minimize exposure.

CONTROL POINT: Design, Operations, Maintenance

(2) Fire or Explosion.
Description: Storage of the materials may cause fire or explosion if these materials are spilled and allowed to mingle with incompatible chemicals.

Control: Controls for fire or explosion include

- Store incompatible materials separately or in secondary containment.
- Consult the manufacturer or the Material Safety Data Sheets for incompatibilities.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

No unique hazards are identified.

d. Biological Hazards.

Pathogenic Microbes.
Description: Biofilters may expose workers to pathogenic microbes, especially during maintenance or repair activities where the reactor may need disassembly or when workers are required to enter the biofiltration vessels. Inhalation of pathogenic microbes may cause allergic reactions or illness. During support media handling activities, workers' hands may be exposed to the microbes and result in accidental ingestion of pathogenic material.

Control: Controls for pathogenic microbes include
- Install partitions or barriers to contain the mist.
- Use HEPA (N100, R100, P100) filter-equipped air-purifying respirators.
- Minimize skin exposure with PPE such as gloves (e.g., butyl rubber) and chemically-resistant disposable coveralls.
- Practice good decontamination by thoroughly washing hands and face before exiting the work area.

CONTROL POINT: Design, Maintenance

Chapter 15
Precipitation

15-1. General.

The process of precipitation, its applications, and resulting waste streams are described in the first section of the chapter. The chapter's second portion is a hazard analysis with controls and control points listed.

15-2. Technology Description.

a. Process.

Precipitation is a treatment process in which soluble metals and inorganics are precipitated into relatively insoluble metals and inorganic salts by the addition of a precipitating agent (see Figure 15-1). Precipitates, which are small or colloidal, are then settled and/or filtered out of solution, leaving a lower concentration of metals and inorganics in the effluent. Precipitating agents include soluble hydroxide, sulfide, carbonate, and xanthate compounds. If the precipitate does not settle rapidly, a polymer may be added as a coagulant to increase agglomeration and settling. Inorganic iron and aluminum derivatives, such as ferric chloride and aluminum, may also be used to enhance coagulation. The solids are settled in a clarifier, and the supernatant liquid is discharged or sent to primary treatment. The thickened solids are then disposed of.

b. Applications.

Precipitation is a primary method of treating metal-contaminated aqueous waste streams. Most metals will precipitate from solution at some concentration of their hydroxide, sulfide, or carbonate salts. Additions of more soluble salts of these compounds to an aqueous stream may precipitate metals whose salts have a lower solubility than the additive ions.

Precipitation is a candidate technology for the remediation of groundwater contaminated with heavy metals (including radionuclides) and is an effective pretreatment method for other remediation technologies (such as chemical oxidation or air stripping) where the presence of metals may interfere with the treatment process.

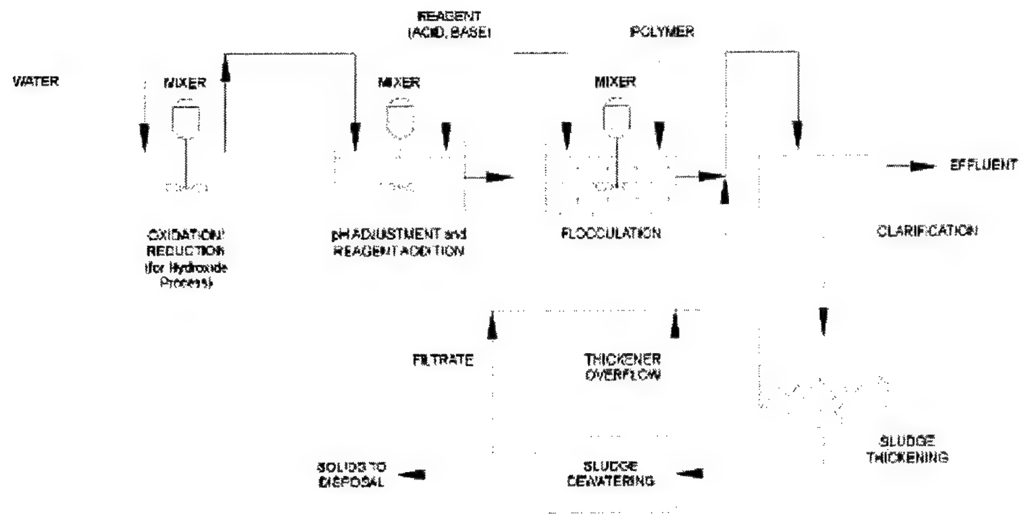


FIGURE 15-1. TYPICAL PROCESS FLOW FOR PRECIPITATION

c. Resulting Waste Streams.

Precipitation reactors will produce two streams that may require additional handling:

- The treated effluent wastewater stream.
- Sludges (such as metal hydroxide sludges) that must pass TCLP tests for land disposal.

Adequate solids separation techniques (such as clarification, coagulation, flocculation, and/or filtration) are required for efficient treatment. Treated effluent may be adversely impacted by the rate of addition of reagents or by pH adjustment, which must be controlled to prevent unacceptable concentrations of total dissolved solids in the treatment effluent.

For additional information on similar processes, see the Chemical Reduction/Oxidation (Chapter 18) and Ultraviolet Oxidation (Chapter 16) technologies.

15-3. Hazard Analysis.

Principal unique hazards associated with precipitation, methods for control, and control points are described below

a. Physical Hazards.

(1) Plugged or Overpressured Waste Lines.

Description: Solids from the precipitation process may plug waste lines if the rate of precipitation exceeds the rate of solids removal. Plugged waste lines may cause tanks to overflow, causing slippery conditions. Also, due to the wet environment and the use of electrical equipment, workers may be exposed to electrocution. Overpressure in lines may also rupture piping or pumps.

Control: Controls for plugged or overpressured lines include

- Use auger-equipped waste lines to help prevent plugged lines.
- Use flow controls to prevent plugged lines and overflowing tanks.
- Install hazard warning alarms to alert operators of system over-pressurization if necessary.
- Allow adequate space for maintenance between equipment.
- Verify that drawings indicate the hazardous area classifications as defined in NFPA 70-500-1 through 500-10.
- Use controls, wiring, and equipment, both temporary and permanent, that conform to EM 385-1-1, Section 11.G and NFPA 70 for the identified hazard areas.
- Use grounded equipment and/or equipment provided with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1, Section 11 or NFPA 70 requirements.
- Permit only trained and experienced workers in the areas.

CONTROL POINT: Design, Operations, Maintenance

(2) Emergency Wash Equipment.
Description: Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards or walking surface hazards during required testing/use.

Control: A control for emergency wash equipment includes

- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping hazards.

CONTROL POINT: Design

(3) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards

(1) Chemical Reagents.
Description: Precipitation treatment may expose workers to corrosive chemical reagents (e.g., HCL, lime, sodium hydroxide, carbonate salts, sulfide salts, etc.) used in the process. The reagents may be in powder or liquid form, and may pose an exposure hazard through either inhalation, dermal, and/or ingestion routes. These reagents may corrode piping system components. Some chemicals used in the precipitation process are hygroscopic (water absorbing) and may develop unwanted reactions in the presence of moisture.

Control: Controls for chemical reagents include

- Use a closed system for the delivery of chemical reagents (e.g., lime, sodium hydroxide solutions, etc.).
- Use personal protective equipment (PPE) such as an air-purifying respirator using cartridges appropriate to the reagents.
- Consult Material Safety Data Sheets (MSDS) prior to handling reagents to determine the specific chemical hazards and face shields, gloves, and aprons required.
- Store hygroscopic chemicals separately from other chemicals in airtight containers.
- Use appropriate materials in the design of piping and system components.

CONTROL POINT: Design, Operations, Maintenance

(2) Uncontrolled Reactions.
Description: If the addition of chemical reagents in oxidation/reduction reactions is not properly controlled, the reaction may cause a heat and pressure buildup that produces a system release. The release may involve worker

exposure to chemical reagents or waste material. Exposure may cause irritation or chemical burns to eyes, skin, and respiratory tracts.

Control: Controls for reactions include

- Use flow controls to help prevent addition of excessive amounts of chemical reagents (e.g., hydrochloric acid, sodium hydroxide, lime, etc).
- Store the oxidation/reduction reagents in separate areas under cool, dry conditions.
- Include pressure-relief systems and over-pressurization alarms as mandatory components in process design.
- Install an automatic shutoff to prevent the overflowing of storage tanks.
- Locate chemical piping low to the ground, if possible, in case of rupture.
- Provide insulation on pipes to prevent slipping hazards if pipes have moisture buildup.

CONTROL POINT: Design

(3) High pH Sludge.
Description: Sludge from the treatment process may have a high pH, which may cause skin burns for workers handling the material.

Control: Controls for high pH include

- Neutralize sludge prior to handling.
- Use PPE such as rain gear, rubber gloves (e.g., butyl rubber for hydrochloric acid or sodium hydroxide), and splash shields.

CONTROL POINT: Design, Operations, Maintenance

(4) Hydrogen Sulfide Exposure.
Description: The process may form metal sulfides, which may generate toxic (including hydrogen sulfide), or the sulfide sludge may spontaneously combust. If sulfide salts are used as a precipitating agent, hydrogen sulfide gas (H&S) will be generated if the solution is acidic.

Control: Controls for hydrogen sulfide exposure include

- Ventilate to remove gas from the work area, process tanks, and vessels.
- Use pH control to keep the sulfides alkaline.
- Use water control systems to keep sulfide filter cakes moist.
- Install a hydrogen sulfide (H_2S) monitor to avoid fatal overexposure where the generation of H_2S is most probable. Set monitors to alarm at 10 ppm.
- Make emergency escape respirators available for all operators in the event of a catastrophic system rupture or uncontrolled reaction.
- Train workers in hazard identification and control.

CONTROL POINT: Design, Operations, Maintenance

(5) Acids and Bases.

Description: Workers may be exposed to acids or bases used for pH adjustment.

Control: Controls for acids and bases include

- Construct secondary containment storage areas for acids and bases of compatible materials.
- Mark storage containers clearly.
- Store acids and bases in separate areas.
- Locate emergency showers and eye wash stations that comply with 29 CFR 1910.151(c) and the design requirements specified in ANSI Z358,1 (1990) near the reagent storage areas.
- Automate handling of pH agents to the extent practical.
- Prepare an emergency plan and train facility personnel to safely handle acids and bases.
- Restrict manual handling of acids and bases to personnel familiar with their properties.
- Use PPE such as leather or rubber acid-resistant boots, chemical-resistant coveralls, goggles and face shields, air-purifying respirators (as indicated by the reagent), and rubber or other acid and base resistant gloves (e.g., nitrile) or gauntlets.
- Train workers in safe acid/base handling techniques.

CONTROL POINT: Design, Operations, Maintenance

(6) Treatment Buildings.
Description: Permanent or semi-permanent treatment buildings may present life safety hazards such as inadequate egress, fire suppression systems, and/or emergency lighting systems.

Control: Controls for treatment buildings include

- Meet the following construction requirements for permanent and semi-permanent treatment system buildings: ANSI 58.1: Minimum Design Loads for Buildings and Other Structures; the National Fire Code; the National Standard Plumbing Code; Life Safety Code; and the Uniform Building Code.
- Make sure structures comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations, or local building codes on Superfund, BRAC, or FUDS sites.

CONTROL POINT: Design, Operations

c. Radiological Hazards.

Radioactive Materials.
Description: Many radioactive materials and naturally occurring radioactive materials (NORM) are metals and if present in the water may be precipitated out

and concentrated. This hazard may be considered out of the ordinary for this technology. Some radioactive materials may present an external exposure hazard. All radioactive materials may present an internal exposure hazard through inhalation or ingestion.

Control: Controls for radioactive materials include
- Consult a qualified health physicist to determine the exposure potential, any necessary engineered controls, or required PPE.

CONTROL POINT: Maintenance

d. Biological Hazards.

No unique hazards are identified.

Chapter 16
Ultraviolet Oxidation

16-1. General.

The process of ultraviolet (UV) oxidation and its applications are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

16-2. Technology Description

a. Process.

UV oxidation is a destructive process that photochemically oxidizes organic and explosive constituents in wastewater by the addition of strong oxidizers, which are activated by irradiation with UV light. The oxidation reactions are achieved through the synergistic action of UV light, in combination with ozone (O_3) and/or hydrogen peroxide (H_2O_2) and/or other catalysts and reagents. Lamps that generate UV light shine on the flow path for the water stream, and the ozone and/or peroxide are injected upstream of the lamps. If complete mineralization is achieved, the final products of the oxidation are carbon dioxide, water, and salts. UV oxidation can use hydrogen peroxide alone, ozone alone, or a combination of hydrogen peroxide and ozone together to treat the aqueous stream.

The main advantage of UV oxidation is that it is a destructive process, as opposed to air stripping or carbon absorption, in which contaminants are extracted and concentrated in a separate phase. The UV oxidation process can be configured in batch or continuous flow modes, depending on the required flow and concentrations. See Figure 16-1.

b. Applications.

The process is effective only for relatively clear aqueous streams. Turbidity in the water will prevent the UV light from fully penetrating the water stream.

For additional information on similar processes, see the Precipitation (Chapter 15) and Chemical Reduction/Oxidation (Chapter 18) technologies.

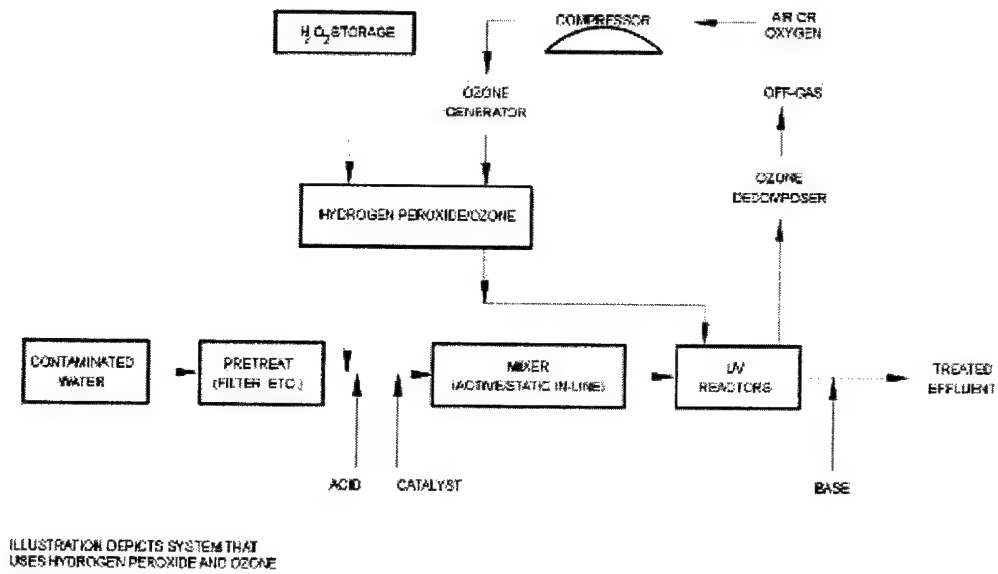


FIGURE 16-1. TYPICAL PROCESS FLOW FOR ULTRAVIOLET OXIDATION

16-3. Hazard Analysis.

Principal unique hazards associated with ultraviolet oxidation, methods for control, and control points are described below.

a. Physical Hazards.

(1) Heated Surfaces.

Description: Certain components of UV treatment systems, such as the UV lamps and the ozone generator, may generate heated surfaces that may cause burns to unprotected skin.

Control: Controls for heated surfaces include
- Insulate or cool surfaces either by ventilation or through a heat exchanger.
- Wear insulated gloves to prevent thermal burns.

CONTROL POINT: Design, Operations, Maintenance

(2) Electrocution.
Description: UV oxidation systems utilize high-voltage mercury lamps that may operate on voltages up to 3,000 volts. Breakage of the lamps may cause electrocution.

Control: Controls for electrocution include
- Verify that drawings indicate the hazardous area classifications as defined in National Fire Protection Association (NFPA) 70-500-1 through 500-10.
- Use controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11.G and NFPA 70 for the identified hazard areas.
- Use grounded or ground fault interrupter circuit (GFIC)-protected equipment if required by EM 385-1-1, Section 11 or NFPA 70.
- Equip UV lamp cover panels with interlocks that de-energize the system when doors are opened.

CONTROL POINT: Design, Construction, Operations, Maintenance

(3) Explosion and Combustion Hazards.
Description: Although hydrogen peroxide solutions (27-52 percent) are not combustible, as strong oxidizers they can greatly intensify combustion. They also present an explosion hazard because of violent decomposition when heated or contaminated with oxidizable materials including iron, copper, brass, bronze, copper, and other metals (see Material Safety Data Sheets for complete listing). Contact with reducing agents or organic and combustible materials (wood, paper) may cause immediate spontaneous ignition.

Control: Controls for explosion include
- Implement a plant-specific lock-out/tag-out program designed after the requirements of 29 CFR 1910.147 for maintenance procedures.
- Implement a plant-specific hazard communication program for plant operators on the reactive properties of hydrogen peroxide. Design in compliance with the requirements of 29 CFR 1910.1200.
- Store hydrogen peroxide solutions in their original containers in a cool, clean, fire-resistant area away from combustible materials, catalytic metals, direct sunlight, and other potential sources of heat and/or ignition.
- Maintain the purity of the solution.
- Do not return unused material to its storage container after removal.
- Select, design, and maintain all equipment in contact with hydrogen peroxide solutions to minimize reactive hazards.
- Use secondary containment in storage areas.
- Supply an ample source of water for handling spills.

CONTROL POINT: Design, Operations, Maintenance

(4) Confined Spaces.

Description: UV oxidation facilities may contain vaults and vessels that require entry as a normal part of operation and maintenance. These spaces have the potential to contain hazardous atmospheres and/or engulfment dangers due to the nature of materials and equipment used in the treatment process.

Control: Controls for confined spaces include

- Eliminate confined space in the design where possible (designers). If confined spaces cannot be eliminated, designers should seek to minimize maintenance requirements in these spaces.
- Ensure that liquid oxygen storage vessels and distribution systems comply with the requirements specified in NFPA 50 and 29 CFR 1910.104 (designers).
- Implement and follow a plant-specific confined-space entry program designed after the requirements of the Occupational Safety and Health Administration's (OSHA's) confined-space standard in 29 CFR 1910.146.
- Implement a plant-specific hazard communication program for plant operators on the hazardous properties of liquid oxygen. Design in compliance with the requirements of 29 CFR 1910.1200.

CONTROL POINT: Design, Operations, Maintenance

(5) Explosion and Fire Hazards.
Description: Operation of UV oxidation systems can generate gases and build pressure in the process units. There is a hazard for the workers for an explosion and release of the reagents and contaminated materials. Some UV/oxidation systems use liquid oxygen to generate ozone. Liquid oxygen storage creates the potential for fire and explosion.

Control: Controls for explosion and fire include

- Include pressure-relief valves and vents discharged away from the work area (designers).
- Consider including alarm systems, monitors to detect pressure build-up, emergency release systems for head spaces, and emergency plans for operations.
- Train workers in hazards associated with all potential gases generated including ozone odor detection.

CONTROL POINT: Design, Operations, Maintenance

(6) Treatment Buildings.
Description: Permanent or semi-permanent treatment buildings may present life safety hazards such as inadequate egress, fire suppression systems, and/or emergency lighting systems.

Control: Controls for treatment buildings include

- Meet the following construction requirements for permanent and semi-permanent treatment system buildings: ANSI 58.1: Minimum Design Loads

for Buildings and Other Structures; the National Fire Code; the National Standard Plumbing Code; Life Safety Code; and the Uniform Building Code.

- Make sure structures comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations, or local building codes on Superfund, BRAC, or FUDS sites.

CONTROL POINT: Design, Operations

(7) UV Radiation.
Description: The operation of a UV-based treatment system utilizes lamps that emit UV radiation that may cause eye damage.

Control: A control for UV radiation includes

- Wear the appropriate ANSI-approved eye protection, utilizing the appropriate shade.

CONTROL POINT: Operations, Maintenance

(8) Noise hazards.
Description: Noise hazards may be associated with the use of an air compressor to generate ozone.

Control: Controls for noise hazards include

- Include isolated generator rooms in building design.
- Develop a hearing protection policy in accordance with 29 CFR 1910.95.

CONTROL POINT: Design, Operations, Maintenance

(9) Emergency Wash Equipment.
Description: Emergency shower/eye wash equipment required per 19 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards or walking surface hazards during required testing/use.

Control: A control for emergency wash equipment includes

- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping hazards.

CONTROL POINT: Design

(10) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Mercury.

Description: Workers may be exposed to mercury if mercury vapor-filled lamps are damaged or broken during installation, inspection, or replacement. Mercury overexposure may cause various symptoms including damage to the central nervous system, conjunctivitis, and inflammation to the nose and throat.

Control: Controls for mercury include

- Handle mercury lamps with caution to help prevent breakage.
- Remove mercury spills immediately.
- Make mercury spill kits available in the immediate work areas.

CONTROL POINT: Construction, Operations, Maintenance

(2) Ozone.

Description: Ozone may be produced via an on-site ozonator to enhance the performance of UV oxidation systems. Ozone may leak through seals or pipe junctions, or ozone levels may increase in the work environment if the ozonator fouls. Ozone is a potential experimental tumorigen and teratogen. Exposure to ozone may irritate exposed skin. Depending upon the degree of exposure, ozone may cause irritation of the eyes and respiratory tract, diminished lung function, pain or difficulty breathing, chest tightness, coughing, wheezing, increased sensitivity of the lungs to allergens and bronchoconstrictors, and increased susceptibility to lung-based bacterial and viral infections.

Control: Controls for ozone include

- Use local or general ventilation of the work area.
- Use closed tops and controlled vents on the UV chambers.
- Use gas-tight covers on sumps and holding tanks downstream of ozone generation systems.
- Vent vessels (passively or actively) through ozone decomposition equipment to the outside of the building.
- Interlock equipment with ozone generation equipment.
- Set equipment to shut ozone generation off if plant levels exceed the ACGIH TLV for ozone.

- Install monitors and alarm systems to warn plant operators if plant levels exceed the ACGIH STEL.
- Implement a plant-specific hazard communication program to identify/address the signs/symptoms of ozone exposure including odor identification and to provide procedures for reducing exposures.

CONTROL POINT: Design, Operations, Maintenance

(3) Catalysts.
Description: Worker inhalation/ingestion/dermal exposure may occur during the use of catalysts used in conjunction with UV oxidation.

Control: Controls for catalysts include
- Minimize all contact with catalysts.
- Wear personal protective equipment (PPE) and clothing such as an air-purifying respirator with HEPA (N100, R100, P100) filters, chemically-resistant disposable coveralls, and protective gloves (e.g., nitrile) based on the materials to be handled.

CONTROL POINT: Design, Operations, Maintenance

(4) Hydrogen Peroxide.
Description: Hydrogen peroxide may also be used to help improve the efficiency of UV oxidation systems. Hydrogen peroxide is an oxidizer that may react violently with organic materials either in the waste stream or in other materials, causing fire or system over-pressurization. Exposure to hydrogen peroxide may cause irritation or chemical burns to the skin and damage eyes. Dermal or eye contact with or inhalation of hydrogen peroxide mists or solutions pose a hazard to personnel due to chemical burns associated with acute exposure.

Control: Controls for hydrogen peroxide include
- Require secondary containment for storage of hydrogen peroxide.
- Feed hydrogen peroxide solutions automatically into the treatment system.
- Use PPE if manual addition of the solutions is required. Gloves made of natural rubber or nitrile offer good chemical resistance to solutions of 30-70 percent hydrogen peroxide. Leather and many fabrics, including cotton, rayon, and wool, should not be worn when handling hydrogen peroxide solutions because they present a fire hazard if spills occur. Instead, wear polyester-acrylic (anti-static treated) garments.
- Wear splash-proof chemical safety goggles and face-shields.
- Use local ventilation or respiratory protection to control mists as determined by a qualified health and safety professional.
- Train workers in hydrogen peroxide hazard identification/control.

CONTROL POINT: Design, Operations, Maintenance

(5) Acids and Bases.
Description: Workers may be exposed to pH control agents (acids and bases) during operations.

Control: Controls for acids and bases include

- Construct secondary containment storage areas for acids and bases and use compatible storage materials.
- Mark storage containers clearly.
- Store acids and bases in separate areas.
- Locate emergency showers and eye wash stations that comply with 29 CFR 1910.151(c) and ANSI Z358,1 (1990) near the reagent storage areas.
- Automate handling of pH agents to the extent practical.
- Prepare an emergency plan and train facility personnel to safely handle acids and bases.
- Restrict manual handling of acids and bases to personnel familiar with their properties.
- Use PPE such as leather or rubber acid-resistant boots, chemical-resistant coveralls, goggles and face shields, air-purifying respirators (as indicated by the reagent), and rubber or other acid and base resistant gloves (e.g., nitrile) or gauntlets.
- Train workers in safe acid/base handling techniques.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

UV Radiation.
Description: The mercury lamps used in the treatment generate high levels of UV radiation. Typically, the UV is contained within the treatment unit. However, radiation that is released may damage eyes or increase the risk of skin cancer.

Control: Controls for UV radiation include

- Equip the reactor vessel with interlocks that de-energize the system when the door is opened.
- Equip viewing ports in reactor walls with glass covers that prevent transmission of UV radiation.

CONTROL POINT: Design, Operations, Maintenance

d. Biological Hazards.

No unique hazards are identified.

Chapter 17
Passive Treatment Walls

17-1. General.

The process of passive treatment walls, installation methods, and their applications are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

17-2. Technology Description.

a. Process.

Passive treatment walls (also called reaction walls) are installed in the ground to treat materials in groundwater that can be readily converted to a non-toxic or inert form. The technology's purpose is to passively route contaminated groundwater through reactive media.

The materials used to construct the wall must:

- Not be made from toxic materials.
- Not produce toxic products or byproducts from the reaction.
- Be thick enough to react with all of the targeted material present.
- Be porous enough to permit the groundwater to flow through.

b. Installation.

Installing the reactive media can be done by a variety of trenching techniques including a backhoe or clamshell. Other techniques for installing the reactive cell include caissons, a continuous trencher, mandrel, or pressurized jetting techniques. For funnel and gate configurations, the funnel walls are placed as impermeable barriers with techniques such as sheet piling or slurry walls. See Figure 17-1 for an example layout.

The wall is installed downgradient from the contaminated groundwater. The water may be channeled or forced to flow through the treatment wall by constructing slurry walls to channel the flow. The method is passive in that the target material flows downgradient dissolved in the groundwater through the reaction wall without pumping or recovery. However, treatment walls typically use destructive or essentially irreversible conversions that chemically and/or biologically alleviate the toxicity problem.

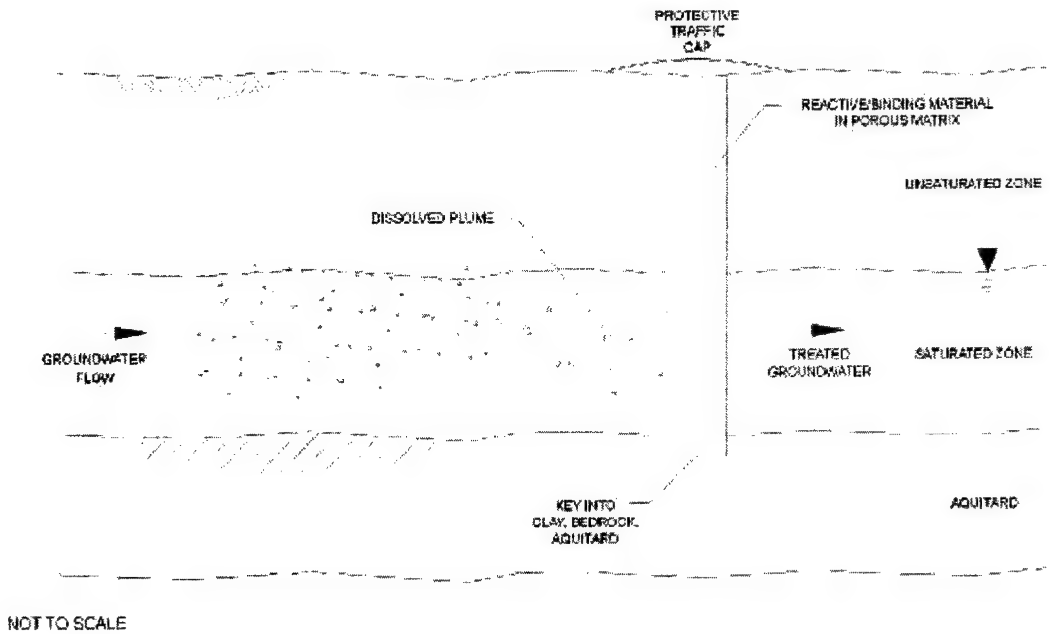


FIGURE 17-1. PASSIVE TREATMENT WALLS

c. Applications.

The technique is most effective for chemicals that are readily soluble in water, have low retardation factors in the subsurface (little interaction with the soil), and are readily reacted into non-toxic forms. An example is the construction of a funnel and gate system containing iron filings as the reactive media for the treatment of TCE in a groundwater plume. The reactive media is designed to react with all of the TCE and its toxic breakdown products such as vinyl chloride.

17-3. Hazard Analysis.

Principal unique hazards associated with passive treatment walls, methods for control, and control points are described below.

a. Physical Hazards.

(1) Equipment Hazards.
Description: During installation of sheet pile walls, workers may be seriously injured or killed by heavy equipment such as front-end loaders, cranes, and pile drivers.

Control: Controls for equipment hazards include

- Use heavy equipment with a backup alarm to alert workers.
- Approach operating equipment from the front and within view of the operator.

CONTROL POINT: Construction

(2) Utility Contact Hazards.
Description: During the excavation of the trench prior to the installation of the passive treatment wall, fire or explosion hazards may exist if excavation equipment ruptures an underground utility such as electrical or gas lines.

Control: Controls for utility contact hazards include

- Contact local utilities and public works personnel to determine the locations of all utilities. When there is any doubt or uncertainty, conduct a utility survey, probe with a metal rod prior to excavation, or hand excavate to determine the exact location of utilities. Once utilities are located, careful excavation by backhoe may be allowed.
- Post an observer to the side to supervise when raising equipment.

CONTROL POINT: Construction

(3) Trench Hazards.
Description: Entry into the trench prior to the addition of slurry material may pose a safety hazard if the trench wall collapses. An inhalation hazard exists if the trench serves as an accumulation point for off gassing of toxic materials (such as chlorinated solvents) from the soil.

Control: Controls for trench hazards include

- Inspect excavations daily.
- Shore walls to prevent collapse according to the requirements of 29 CFR 1926.650-652.
- Consider trench entry as a confined-space entry (see 29 CFR 1910.146).
- Test the atmosphere within the excavation to determine the level of airborne contaminants prior to entry.

CONTROL POINT: Construction

(4) Steam Pressure Washing.
Description: Steam pressure washing of equipment may expose workers to thermal or burn hazards, eye hazards due to flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control: Controls for steam pressure washing include

- Use insulated gloves (e.g., silica fabric gloves).
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.

- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(5) Respirable Quartz Hazard.
Description: Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422, followed by analysis of the fines by X-ray diffraction to determine fine material quartz content.

Control: Controls for respirable quartz include
- Wet the soil periodically with water or amended water to minimize worker exposure.
- Use respiratory protection, such as an air-purifying respirator equipped with a HEPA (N100, R100, P100) filter.

CONTROL POINT: Design, Construction, Operations

(6) UV (Ultraviolet) Radiation.
Description: During site activities, workers may be exposed to direct and indirect sunlight and corresponding UV radiation. Even short-term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control: Controls for UV radiation include
- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen.
- Shade work and break areas if possible.
- Minimize exposure to heat stress by taking frequent breaks, drinking adequate fluids, and performing work during the early morning and late afternoon hours.

CONTROL POINT: Construction, Operations

(7) Electrocution.
Description: Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control: Controls for electrocution include
- Note overhead power line location, either existing or proposed, in the pre-design phase.
- Keep all lifting equipment, such as cranes, forklifts, and pile drivers at least 10 feet from a power line according to Occupational Safety and Health

- Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.E.

CONTROL POINT: Design, Construction, Operations

(8) Traffic Hazards.
Description: During the implementation of field activities, equipment and workers may come in close proximity to traffic. Also, equipment may need to cross or use public roads. The general public may be exposed to traffic hazards and the potential for accidents.

Control: Controls for traffic hazards include
- Post warning signs according to the criteria of the Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways.
- Develop a traffic management plan before remediation activities begin to help prevent accidents. EM 385-1-1, Section 21.I10 provides plan details.

CONTROL POINT: Design, Construction, Operations

(9) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include
- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Contaminants (Soil).
Description: Workers may be exposed via the inhalation, ingestion, dermal exposure routes to the contaminants during the excavation of the trench if the excavation is made in contaminated soil. Dusts and volatile organic compounds (VOCs) entrained with waste materials may become airborne during the excavation, exposing workers to the waste material.

Control: Controls for contaminants in the soil include
- Place the trench outside the area of contamination to the extent practical.

- Apply water to control airborne dusts.
- Use PPE such as an air-purifying respirator with organic vapor cartridges to help control worker exposure.

CONTROL POINT: Design, Construction, Operations

(2) Treatment Wall.
Description: Workers may be exposed to materials such as iron pyrites, coal (dust), metal chelators, and microbes used as the treatment medium during installation of the treatment wall. In addition, metals or other contaminants in the wall material may pose a higher risk during replacement or maintenance operations.

Control: Controls for chemicals in treatment walls include
- Wet materials periodically to control airborne dust.
- Use PPE selected by a qualified health and safety professional based on the contaminants in the wall matrix. For example, for chelated metals, use an air-purifying respirator with HEPA (N100, R100, P100) filters, chemically-resistant coveralls, and water/chemical impervious gloves (e.g., nitrile).

CONTROL POINT: Construction, Maintenance

c. Radiological Hazards.

No unique hazards are identified.

d. Biological Hazards.

No unique hazards are identified.

Chapter 18
Chemical Reduction/Oxidation

18-1. General.

The process of reduction/oxidation (redox), its applications, and resulting waste streams are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

18-2. Technology Description.

a. Process.

Redox reactions chemically convert hazardous contaminants to nonhazardous or less hazardous compounds that are more stable, less mobile, less toxic, or inert. This is accomplished by chemical reactions that involve electron transfer (and usually other chemical groups) from one reactant (oxidized compound) to another compound (reduced compound).

As shown in Figure 18-1, excavated soil is screened and oversized rejects are combined with the sludge for disposal. Water is added to the screened soil, and the slurry is transferred to a reactor, where reagents (such as ozone, hydrogen peroxide, hypochlorites, chlorine, or chlorine dioxide) are added to react with targeted constituents. The reagent/soil mixture is transferred to a separator, where excess reagent is removed and recycled back into the reactor. The treated soil is washed and dewatered. Water from the dewatering process is recycled back to the soils washer. The dewatered sludge is combined with oversized rejects for disposal.

b. Applications.

Chemical redox is an established technology for the disinfection of drinking water and wastewater. Ultraviolet (UV) oxidation is an example of a UV-stimulated version of this treatment approach. The technology can be applied to both liquid and solid wastes.

The target contaminants for redox reactions are usually inorganic species, especially cyanide or chromium-containing wastes, but can also be phenols and other readily oxidized organics. The technology is less effective for nonhalogenated volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), fuel hydrocarbons, pesticides, and high contaminant concentrations. Oil and grease in the waste should be minimized to prevent excessive side reactions and increase process efficiency.

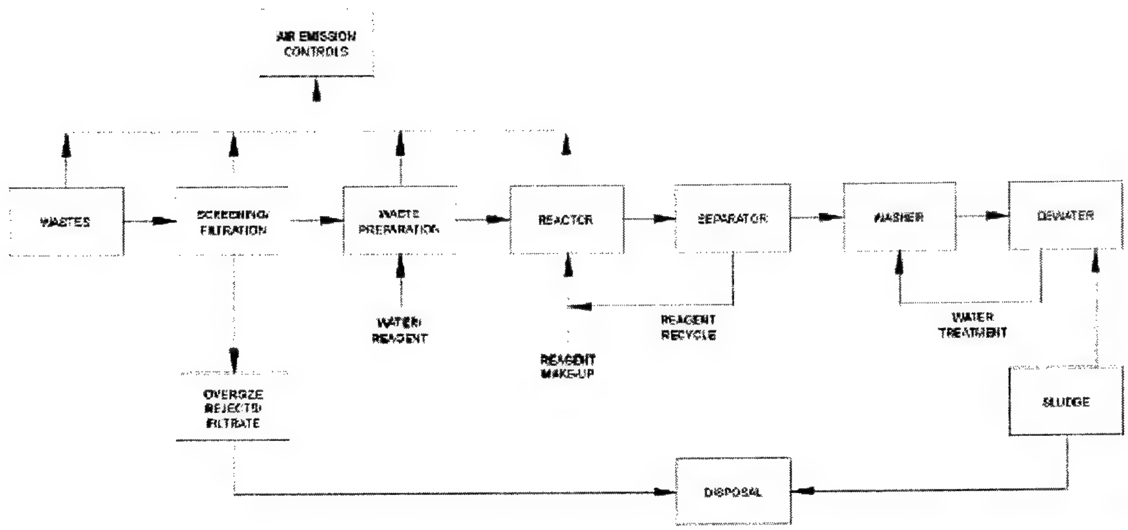


FIGURE 18-1. TYPICAL PROCESS FOR CHEMICAL REDUCTION/OXIDATION PROCESS

c. Resulting Waste Streams.

The technology produces three streams that may require additional handling:

- Emissions from soil excavation (requires additional treatment).
- Effluent water from dewatering (may be recycled or may be discharged after treatment).
- Sludge and oversized rejects (may require additional treatment prior to disposal).

If the process is not optimized, formation of intermediate contaminants or incomplete oxidation (such as organic acids or aldehydes) may occur.

For additional information on similar processes, see the Precipitation (Chapter 15) and Ultraviolet Oxidation (Chapter 16) technologies.

18-3. Hazard Analysis.

Principal unique hazards associated with chemical reduction/oxidation, methods for control, and control points are described below.

a. Physical Hazards.

(1) Incompatible Reagents.
Description: Because of the reactive nature of the chemical reagents (e.g., sulfuric acid, ozone, hyperchlorites), the system design and materials of construction must be compatible with the reagents. Incompatible reagents and materials may cause fire or system over-pressurization and explosion.

Control: Controls for incompatible reagents include

- Use liquid transfer equipment (pumps, piping, pipe fittings, valves, and instruments) fabricated from materials that are chemically-resistant to the liquid streams. Hydraulic Institute standards HI 9.1-9.5 discuss appropriate materials for pumping various fluids. Typical chemical charts can be found through the National Association of Corrosion Engineers (NACE).
- Provide chemical handling procedures.
- Substitute equipment during construction only if authorized by the design engineer.

CONTROL POINT: Design, Construction, Maintenance

(2) Uncontrolled Reactions.
Description: Runaway reactions (such as mixing concentrated acids or bases without sufficient cooling or dilution) that generate excessive heat and pressure within the system may cause fire or explosion.

Control: Controls for reactions include

- Monitor the injection of reagents into the process.
- Monitor the process temperatures at critical points.
- Provide for automatic feed shutdowns at preset temperatures.

CONTROL POINT: Design, Operations, Maintenance

(3) Flushing Agents.
Description: Prior to startup of the treatment unit, the system may be flushed with cleaning fluids that may be incompatible with the chemical reagents (e.g., chlorine, hyperchlorites) used in the treatment process. The commingling of these materials cause heat and pressure buildup within the system, possibly resulting in an explosion.

Control: A control for flushing agents includes

- Determine the compatibility of the flushing agents and the reagents prior to their introduction into the system.

CONTROL POINT: Operations, Maintenance

(4) Plugged Waste Lines.
Description: Sludge from the chemical reduction/oxidation process may plug waste lines if the rate of precipitation exceeds the rate of sludge removal. Plugged lines may result in an explosion from system over-pressurization or fire from the pump motor overheating.

Control: Controls for plugged waste lines include
- Use auger-equipped waste lines or flow controls.
- Install hazard warning alarms to alert operators of system over-pressurization.

CONTROL POINT: Design, Operations, Maintenance

(5) Tank Mixing Equipment.
Description: Tank mixing equipment may splash chemical reagents (e.g., acids or hydrogen peroxide) or may entangle workers who come in contact with propellers or shafts.

Control: Controls for mixing equipment include
- Use tanks designed to protect people from harmful splashing of rotating mixers or entanglement with shafts or motors.
- Implement lock-out/tag-out procedures when performing maintenance activities on the mixers.
- Train workers in potential chemical contact hazards and control measures (see 29 CFR 1910.1200).

CONTROL POINT: Design, Operations, Maintenance

(6) Electrical Shock.
Description: Electrical systems in wet or damp areas can cause electrical shock to operating personnel.

Control: Controls for electrical shock include
- Use ground-fault protected electrical systems in areas that could become wet or damp. Electrical system design must follow National Electrical Code NFPA 70 and CEGS 16415 (Electrical Work, Interior).
- Use grounded and/or GFIC-protected equipment if required by EM 385-1-1, Section 11 or NFPA 70.

CONTROL POINT: Design, Construction, Operations, Maintenance

(7) Emergency Wash Equipment.
Description: Emergency shower/eye wash equipment required per 19 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards or walking surface hazards during required testing/use.

Control: A control for emergency wash equipment includes

- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping hazards.

CONTROL POINT: Design

(8) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Chemical Reagents (Use and Storage).
Description: Hazardous waste treatment using chemical reduction and oxidation poses worker chemical exposure due to the use and storage of toxic and reactive chemical reagents such as ozone and hydrogen peroxide. The reagents may react under certain conditions to generate heat and pressure within their storage containers. Spills involving the mixing of incompatible reagents may generate toxic vapors (such as hydrogen or chlorine) or generate sufficient heat to ignite combustible materials.

Control: Controls for chemical reagents include

- Label all tanks and piping systems.
- Use temperature and moisture control in storage areas.
- Segregate storage areas by dikes.
- Use spill control equipment.
- Determine reagent compatibility prior to placement in storage and following their introduction into the system.
- Consult Material Safety Data Sheets to determine the specific chemical hazards associated with the reagent chemicals and train workers in hazard avoidance techniques (see 29 CFR 1910.1200).

CONTROL POINT: Design, Operations, Maintenance

(2) Chemical Reagent Exposure.
Description: Chemical reagents are listed in CEGS 11242, Chemical Feed Systems. Workers may be exposed to these chemical reagents and/or to byproducts of chemical reduction/oxidation via the inhalation/ingestion/dermal exposure routes. Materials may be toxic (such as carbon monoxide and chlorine) or explosive (as with hydrogen).

Control: Controls for chemical reagent exposure include

- Pressure test all piping connections.
- Consult Material Safety Data Sheets to determine the specific health hazards associated with the specific chemical reagents utilized in the process. Material Safety Data Sheets describe the specific personal protective equipment (PPE) required and appropriate neutralization measures in the event of a spill or exposure.
- Test the atmosphere inside tanks prior to each entry (see 29 CFR 1910.146).
- Ventilate the system to prevent the accumulation of hydrogen, chlorine, or other toxic and explosive gases.
- Equip areas where byproducts, such as carbon monoxide, chlorine, and hydrogen, are generated with local exhaust ventilation. If the generation of ozone, CO, Cl_2, and/or hydrogen is significant and cannot be properly exhausted, install carbon monoxide and/or hydrogen monitors with visual and audible alarms to alert operators.

CONTROL POINT: Design, Operations, Maintenance

(3) Improper Chemical Amounts.
Description: Effluent water may contain significant concentrations of reagents that can cause dermal and ocular damage. In instances where too much chemical has been used, the residual chemical can cause reactions and high temperatures. The under use of chemicals can cause incomplete process reactions that may cause over-pressurization of the system and subsequent leaks.

Control: Controls for chemical amounts include

- Use oxidation and/or reduction mixing/retention tanks with monitors and alarms for chemical dosages or operational temperatures that exceed preset limits.
- Include control logic in facility design to shut down chemical transfer systems under upset conditions.

CONTROL POINT: Design, Construction, Operations, Maintenance

(4) Chemical Reagents (Compatibility).
Description: Flushing the system prior to startup may cause chemical reactions and increased pressure with the reagents during system operation.

Control: A control for chemical reagents includes

- Review the compatibility of the chemical reagents used in system operation prior to addition/mixing of these reagents.
- Make Material Safety Data Sheets, in accordance with ANSI 2400.1, available to operators.

CONTROL POINT: Design, Operations, Maintenance

(5) Chemical Exposure From Equipment Failure.
Description: Reactive chemicals used in the process may corrode pipes, gaskets, and connectors causing leaks and worker exposure. Workers may be exposed to reactive chemical reagents including hydrogen peroxide, hypochlorites, and chlorine.

Control: Controls for chemical exposure resulting from equipment failure include

- Design/construct process equipment with compatible materials. Consult Hydraulic Institute standards HI 9.1-9.5 (Pumps - General Guidelines) for appropriate selection of materials.
- Feed reagent chemicals automatically into the system via a closed piping system.
- Wear proper PPE for the reagents if manual addition is required.
- Train workers in potential chemical hazards and controls (see 29 CFR 1910.1200).

CONTROL POINT: Design, Operations, Maintenance

(6) Contaminants (Screening Process).
Description: When screening contaminated materials, employees may be exposed, via dermal or inhalation routes, to soils, sludge, dust, or oversized rejects.

Control: Controls for exposure to contaminants include

- Use water during soil screening to minimize the amount of dust generated.
- Perform dust monitoring if necessary to determine when respiratory protection such as air-purifying respirators equipped with HEPA (N100, R100, P100) filters should be donned.
- Wear chemical-resistant coveralls and chemical-resistant gloves (e.g., nitrile) to prevent direct contact with the contaminated soils. Such controls prevent workers from carrying any contamination home on their clothing.

CONTROL POINT: Operations

c. Radiological Hazards.

No unique hazards are identified.

d. Biological Hazards.

No unique hazards are identified.

Chapter 19
Liquid-Phase Carbon Adsorption

19-1. General.

The process of liquid-phase carbon adsorption and its applications are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

19-2. Technology Description

a. Process.

Liquid-phase carbon adsorption is a remediation technology in which contaminated water is pumped through activated carbon in a vessel or series of vessels. Dissolved contaminants may adsorb to the carbon. When the carbon becomes saturated with the contaminants, the activated carbon can be regenerated in place, removed and regenerated off site, or removed and disposed of. Carbon used for explosives or metals-contaminated water probably can not be regenerated and should be removed and properly disposed of. Adsorption by activated carbon has a long history of use in treating municipal, industrial, and hazardous waste streams. See Figure 19-1.

Each specific chemical has a different affinity for the activated carbon sites depending on that chemical's properties and configuration, and thus each chemical is adsorbed to a different degree (and mass ratio). Adsorption isotherms for many organic chemicals are available from manufacturers of the activated carbon. These isotherms predict what weight of the chemical will be adsorbed at equilibrium conditions for specified temperatures per unit weight of carbon.

The technology is not directly destructive, but binds the contaminants to a more concentrated medium for post-treatment destruction, permitting the higher volume clean water stream to be safely discharged to the environment.

b. Application.

Activated carbon's effectiveness as a treatment is always a function of the specific chemicals being treated, the combination of chemicals being treated, the unit's hydraulic residence time, temperature, and other factors. Activated carbon is most effective in adsorbing non-polar molecules and aromatic hydrocarbons. Chlorinated volatile organic compound (VOC) species are generally not adsorbed as well as their hydrocarbon analogues. Multi-ring compounds are very strongly adsorbed, and so

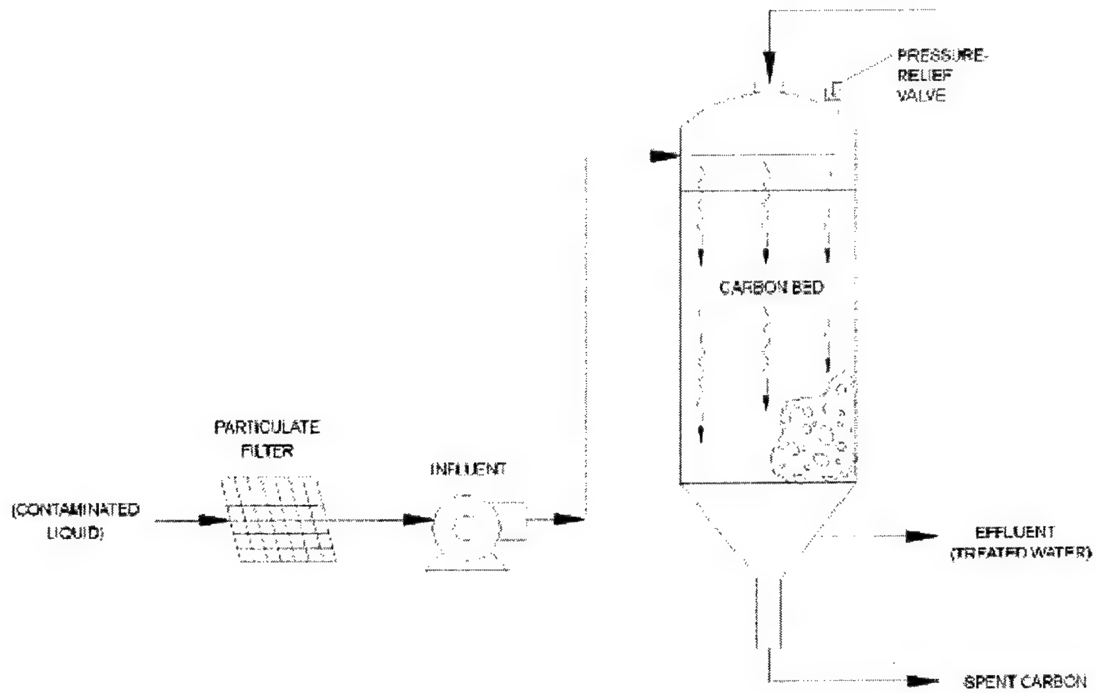


FIGURE 19-1. LIQUID-PHASE CARBON ADSORPTION

the method is particularly effective with polyaromatic hydrocarbons (PAHs). Polychlorinated biphenyls (PCBs) are also strongly adsorbed. Short VOC alkanes and alkenes are less well-adsorbed, including many chlorinated VOCs. Oxygenated solvents and very small organic molecules (e.g., acetone, MEK, and vinyl chloride) may not be adsorbed to any useful degree at all.

This technology is well suited to streams with low concentrations of the organics of concern. Streams with relatively high organic loadings will require more carbon per unit of flow than more dilute streams. The ability of the carbon to adsorb metals is limited.

19-3. Hazard Analysis.

Principal unique hazards associated with liquid-phase carbon adsorption, methods for control, and control points are described below.

a. Physical Hazards.

(1) Confined Spaces.

Description: Entering the carbon bed tanks for activities such as inspection, repair, and maintenance may constitute a confined-space entry. Hazards associated with entry into confined space include asphyxiation from the lack of oxygen, exposure to toxic wastes, inhalation of fine carbon particles and byproducts, and engulfment/entrapment by the carbon bed.

Control: Controls for confined spaces include

- Implement a confined-space entry program. Include atmosphere testing inside the tanks (see 29 CFR 1910.146).
- Use appropriate personal protective equipment (PPE) such as an air-purifying respirator with filter/cartridge if necessary.

CONTROL POINT: Operations, Maintenance

(2) Plugged Waste Lines.
Description: Sludge from the waste may plug transfer lines or piping at slow flow velocities. Plugged waste lines may cause tanks to increase pressure, possibly causing a leak that exposes workers to waste material.

Control: Controls for plugged waste lines include

- Include adequate flow controls and pipe velocities in design.
- Use filters to remove solids prior to carbon bed treatment.
- Implement a routine system operation inspection.

CONTROL POINT: Design, Operations, Maintenance

(3) Spent Carbon.
Description: Spent carbon used to remove explosive contaminants and other types of organic chemicals from water is a potential explosion and fire hazard during regeneration and removal from the tank.

Control: A control for spent carbon includes

- Do not regenerate spent carbon used to remove potentially explosive contaminants (e.g., explosives, highly volatile organic chemicals). Heat used to regenerate the carbon may ignite or explode the adsorbed material.

CONTROL POINT: Design, Operations, Maintenance

(4) Carbon Holding Tanks/Drums.
Description: Carbon holding tanks or drums may leak or spill over into the surrounding areas, resulting in worker exposure during operations or loading and unloading of carbon.

Control: Controls for carbon holding tanks/drums include

- Equip holding tanks or drums with adequate spill containment.
- Install spill and/or leak monitors and alarms if necessary.
- Train workers in potential safety and health hazards.

CONTROL POINT: Design, Operations, Maintenance

(5) Water Transfer Equipment.
Description: Water transfer system equipment (pumps, piping, pipe fittings, valves, and instruments) in contact with contaminated liquids can corrode or dissolve to a point of failure and cause facility damage or worker exposure to waste chemicals.

Control: Controls for water transfer equipment include

- Use water transfer system equipment fabricated from materials that are chemically-resistant to the contaminants in the system.
- Consult Hydraulic Institute standards HI 9.1-9.5 for appropriate pumping materials. Typical chemical resistance charts can be found through the National Association of Corrosion Engineers (NACE).
- Include containment drip pans or receivers where leaks may occur.
- Install spill and/or leak detection instruments if necessary.
- Implement a routine system operation inspection.

CONTROL POINT: Design, Construction, Maintenance

(6) Over-Pressurization.
Description: Carbon beds are normally operated under pressure. Over-pressurization may result in explosion or fire from overheating of the pump motor.

Control: Controls for over-pressurization include

- Hydro test all systems in accordance with CEGS 11225 (Downflow Liquid Activated Carbon Adsorption Units) before the system is put into operation.
- Add warnings for contents under pressure.

CONTROL POINT: Design, Construction

(7) Plugged Carbon Bed (Biological Growth).
Description: Under certain operating conditions, biological growth can occur inside carbon beds. This growth may foul or plug the carbon bed flow pores, which may cause an increase in back pressure on the system. The back pressure may cause worker exposure to chemicals due to system leaks.

Control: Controls for biological growth include

- Feed biocides into the system on a periodic basis if appropriate.
- Back-wash with biocides or bleaches to minimize or remove the biological growth.
- Replace, regenerate, or dispose of the carbon.

CONTROL POINT: Maintenance

(8) Electrical Shock.
Description: Electrical systems in wet or damp areas can cause electrical shock to operating personnel.

Control: Controls for electrical shock include
- Verify that drawings indicate hazardous area classifications as defined in NFPA 70-500-1 through 500-10.
- Use controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11.G; NFPA 70; and CEGS 16415: Electrical Work, Interior.
- Use grounded equipment and/or equipment with ground fault interrupter circuit (GFIC) protection if required by EM 385-1-1, Section 11 or NFPA 70 requirements.

CONTROL POINT: Design, Construction, Operations, Maintenance

(9) Treatment Buildings.
Description: Permanent or semi-permanent treatment buildings may present life safety hazards such as inadequate egress, fire suppression systems, and/or emergency lighting systems.

Control: Controls for treatment buildings include
- Meet the following construction requirements for permanent and semi-permanent treatment buildings: ANSI 58.1: Minimum Design Loads for Buildings and other structures; the National Fire Code; the National Standard Plumbing Code; Life Safety Code; and the Uniform Building Code.
- Make sure structures comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations, or local building codes on Superfund, BRAC, or FUDS project sites.

CONTROL POINT: Design, Operations

(10) Fire.
Description: Fires may result when this treatment technology is used for some components in wastes. For example, hydrogen sulfide may cause carbon bed fires because of its high heat release upon adsorption, or peroxides may auto-ignite.

Control: A control for fire includes
- Select an alternate technology during design if the known or anticipated contaminants pose an unmanageable threat of fire.

CONTROL POINT: Design

(11) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

Waste Chemical Exposure (Tank/Pipe Corrosion).
Description: Workers may be exposed to waste chemicals from system leaks when activated carbon corrodes tanks and piping systems made from carbon steel.

Control: Controls for chemical exposure include

- Do not use carbon steel to contain activated carbon.
- Use stainless steel, thermoplastic, or other chemically-resistant tank materials.
- Paint, coat, or line tank interiors to prevent contact between activated carbon and carbon steel.
- Train workers in potential chemical exposure hazards and controls (see 29 CFR 1910.1200).

CONTROL POINT: Design, Construction, Maintenance

c. Radiological Hazards.

Radioactive Material.
Description: In some geological settings, dissolved naturally occurring radioactive materials (NORM) or radioactive contaminants may be drawn up with the groundwater. Depending on the chemical form, the radioactive component may be trapped by the activated carbon and concentrated in the filter to a point where a radiation hazard may develop.

Control: A control for radioactive material includes

- Consult a qualified health physicist if elevated levels of NORM or radioactive contaminants are in the groundwater.

CONTROL POINT: Maintenance

d. Biological Hazards.

No unique hazards are identified (see Physical Hazard item 7, "Plugged Carbon Bed").

Chapter 20
Vapor-Phase Carbon Adsorption

20-1. General.

The process of vapor-phase carbon adsorption and its applications are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

20-2. Technology Description.

a. Process.

Activated carbon may be used to adsorb organic compounds from an air stream traveling through the activated carbon in a vessel. The volatile organic compounds (VOCs) in the air stream are adsorbed from the stream and the effluent discharged to the atmosphere. In general, the vapor-phase canisters will adsorb more hydrocarbon mass per mass of activated carbon than the liquid system (see Chapter 20). Thus, for some sites where the compounds of concern are VOCs, air stripping to change the phase of the VOCs to vapor, followed by vapor-phase carbon adsorption, may be less expensive than liquid-phase carbon adsorption alone. Vapor-phase carbon adsorption is also used in conjunction with air stripping and soil vapor extraction (SVE) to remove compounds of concern from the vapor stream prior to its release to the atmosphere. See Figure 20-1.

In this treatment process, no compounds are altered chemically, only concentrated in the carbon filter media as the higher volume clean air stream is discharged to the environment. The technology is not directly destructive, but binds the contaminants to a more concentrated medium for post-treatment destruction.

b. Applications.

This technology is applicable to the removal of VOCs and some semi-volatile organic compounds (SVOCs) from vapor streams. Compounds that cannot be readily volatilized in air are not extracted. Each specific chemical has a different affinity for the activated carbon sites depending on that chemical's properties and conformation, and thus each chemical is adsorbed to a different degree (and mass ratio).

Adsorption isotherms for many organic chemicals are available from manufacturers of the activated carbon. These isotherms predict what weight of the chemical will be adsorbed at equilibrium conditions for specified temperatures per unit weight of carbon.

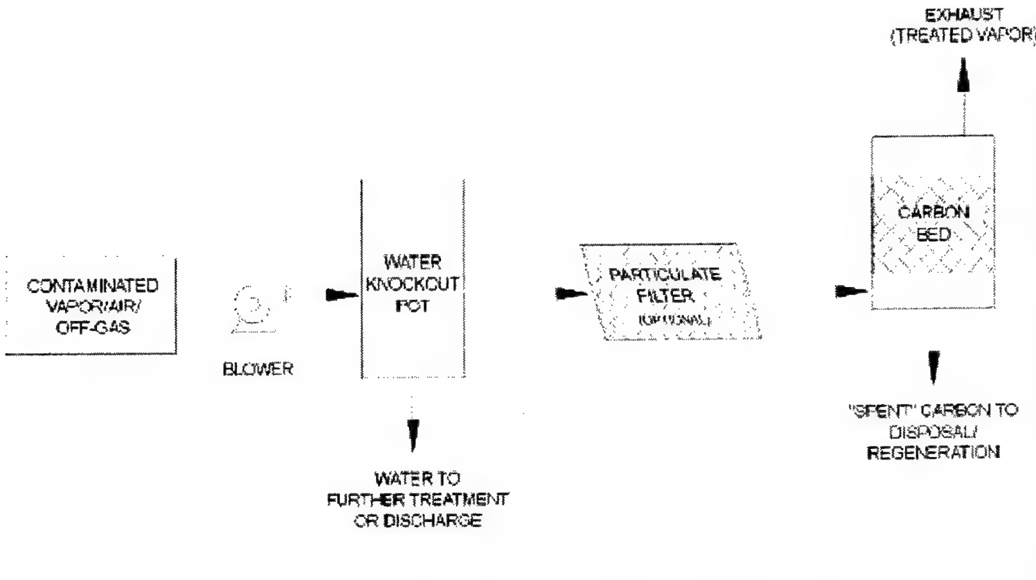


FIGURE 20-1. VAPOR PHASE CARBON ADSORPTION

Activated carbon's effectiveness as a treatment is always a function of the specific chemicals being treated, the combination of chemicals being treated, the unit's hydraulic residence time, temperature, and other factors. Activated carbon is most effective in adsorbing non-polar molecules and aromatic hydrocarbons. Chlorinated VOC species are generally not adsorbed as well as their hydrocarbon analogues. Multi-ring compounds are very strongly adsorbed, and so the method is particularly effective with polyaromatic hydrocarbons (PAHs). Polychlorinated biphenyls (PCBs) are also strongly adsorbed. Short VOC alkanes and alkenes are less well-adsorbed, including many chlorinated VOCs. Oxygenated solvents and very small organic molecules (e.g., acetone, MEK, and vinyl chloride) may not be adsorbed to any useful degree at all.

Air streams that contain compounds that may form peroxides in air or otherwise auto-ignite are of particular concern when using vapor-phase activated carbon adsorption. Compounds such as hydrogen sulfide are adsorbed exothermically and may generate enough heat to create a fire hazard by igniting the activated carbon beds.

20-3. Hazard Analysis.

Principal unique hazards associated with vapor-phase carbon adsorption, methods for control, and control points are described below.

a. Physical Hazards.

(1) Fire Hazards (Waste Components).
Description: Fires may result when this treatment technology is used for treatment of some components in wastes. For example, hydrogen sulfide may cause carbon bed fires because of its high heat release upon adsorption, or peroxides may auto-ignite.

Control: A control for fire includes

- Select an alternate technology during design if the known or anticipated contaminants pose an unmanageable threat of fire.

CONTROL POINT: Design

(2) Confined Spaces.
Description: Entering the carbon bed tanks for activities such as inspection, repair, and maintenance may constitute a confined-space entry. Hazards associated with entry into confined space include asphyxiation from the lack of oxygen, exposure to toxic wastes or microbial growth on the carbon, and engulfment/entrapment by the carbon bed.

Control: Controls for confined-space entry include

- Implement a confined-space entry program to assess hazards (see 29 CFR 1910.146).
- Include atmosphere testing inside the tanks.

CONTROL POINT: Operations, Maintenance

(3) Fire or Explosion (Gas Transfer).
Description: During the transfer of flammable or combustible gases to the adsorption bed, a fire or explosion hazard may exist if equipment is not approved for flammable locations or if static electricity is discharged. Fire can also occur during removal of carbon from the vessel.

Control: Controls for fire during gas transfer include

- Verify that drawings indicate the hazardous area classifications, as defined in NFPA 70-500-1 through 500-10.
- Use controls, wiring, and equipment on and near the beds that meet the requirements of EM 385-1-1, Section 11.G and NFPA 70.
- Bond transfer systems properly and ground to help prevent static discharge if required by EM 385-1-1, Section 11.G or NFPA 70.
- Permit only trained, experienced workers to work around the beds.

CONTROL POINT: Design, Construction, Operations, Maintenance

(4) Carbon Holding Tanks/Drums.
Description: Carbon holding tanks or drums containing VOC-saturated carbon may leak or spill over into the surrounding areas during operations or loading and unloading of carbon. The resulting spill may be easily ignited. Conditions during which the carbon may be heated may increase this risk.

Control: Controls for carbon holding tanks/drums include
- Equip carbon holding tanks or drums with adequate spill containment.
- Install spill and/or leak detection monitors and alarms when appropriate.
- Verify that drawings indicate the hazardous area classifications as defined in NFPA 70-500-1 through 500-10.
- Use controls, wiring, and equipment on or near the tanks or drums that meet the requirements of EM 385-1-1, Section 11.G and NFPA 70.
- Mark all electrical systems properly for potential hazards.
- Permit only trained and experienced workers in tank/drum areas.
- Ventilate storage areas adequately to help prevent the accumulation of VOCs.

CONTROL POINT: Design, Construction, Operations, Maintenance

(5) Vapor Transfer Equipment Design.
Description: Vapor transfer equipment (pumps, fans, blowers, piping, pipe fittings, valves, and instruments) in contact with contaminated vapors can corrode or dissolve, causing damage to the facilities or exposure to workers. The result may cause an explosion of a pipe or other vessel.

Control: Controls for vapor transfer equipment include
- Use vapor transfer equipment (pumps, fan, blowers, piping, pipe fittings, valves and instruments) fabricated from materials that are chemically-resistant to contaminants in the system.
- Consult Hydraulic Institute standards HI 9.1-9.5 for appropriate pumping materials. Chemical resistance charts are available through the National Association of Corrosion Engineers (NACE).

CONTROL POINT: Design, Construction, Maintenance

(6) Fires or Explosion (Carbon).
Description: Carbon beds can be operated under pressure or vacuum. Systems designed to operate under pressure (e.g., fans, pumps, or blowers upstream from the carbon bed) have a potential risk of flammable vapor leakage that may explode if ignited. Carbon dust can also be ignited and cause explosions. Reactions of chemicals, such as ketones, with activated carbon can be exothermic and cause fires or explosions.

Control: Controls for fire or explosion include

- Use containment drip pans or receivers where leaks may occur.
- Install spill and/or leak detection instruments if necessary.
- Design tanks and piping around pressurized carbon beds for the maximum operating pressure expected.
- Install over-pressure instrumentation (usually required) to decrease the possibility of uncontrolled or fugitive vapor releases. These instruments can be set to shut down fans, blowers, or pumps.
- Assess the compatibility of the contaminants and the carbon bed needs to prevent exothermic reactions.
- Handle carbon to minimize the generation of explosive dust or fines.
- Design the system to minimize the potential for electrical spark or open flame, particularly during change out of carbon.

CONTROL POINT: Design, Construction, Operations, Maintenance

(7) Temperature Control.
Description: Vapor-phase carbon systems operate better if the inlet vapors are at or below 50 percent relative humidity. Inlet heaters may be used. However, if the inlet vapors are overheated, spontaneous ignition of the carbon beds can occur.

Control: Controls for temperature include

- Install temperature control instrumentation to monitor the operating temperature of the system.
- Use an alarm and/or automatic heat, fan, blower, or pump shutdown if the carbon bed temperature exceeds 120° F (50° C).

CONTROL POINT: Design, Operations, Maintenance

(8) Electrical Shock.
Description: Electrical systems can cause electrical shock to operating personnel.

Control: Controls for electrical shock include

- Verify that drawings indicate the hazardous area classifications, as defined in NFPA 70-500-1 through 500-10.
- Use controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11.G; NFPA 70; and CEGS 16415: Electrical Work, Interior for the identified hazard areas.
- Post typical electrical hazard warning signs.

CONTROL POINT: Design, Construction, Operations, Maintenance

(9) Treatment Buildings.
Description: Permanent or semi-permanent treatment buildings may present life safety hazards such as inadequate egress, fire suppression systems, and/or emergency lighting systems.

Control: Controls for treatment buildings include

- Meet the following construction requirements for permanent and semi-permanent treatment buildings: ANSI 58-1: Minimum Design Loads for Buildings and Other Structures; the National Fire Code; the National Standard Plumbing Code; Life Safety Code; and the Uniform Building Code.
- Make sure structures comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations, or local building codes on Superfund, BRAC, or FUDS project sites.

CONTROL POINT: Design, Operations

(10) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) VOC Exposure (Exhaust).

Description: If the vapor-phase carbon adsorber becomes saturated or is operated on hot days, VOCs may be adsorbed less efficiently by the carbon, causing an increase in VOC concentration in the exhaust. Workers in the area of the exhaust may be exposed to VOCs.

Control: Controls for VOCs exposure include

- Monitor the discharge for VOCs and shut down the system if the VOC inlet concentration exceeds a predetermined level.
- Use respiratory protection (an air-purifying respirator with organic vapor cartridges) to control exposures.

- Train workers in potential chemical exposure hazards and controls (see 29 CFR 1910.1200).

CONTROL POINT: Design, Operations, Maintenance

(2) VOC Exposure (Breakthrough of Carbon Bed).
Description: Workers may be exposed to VOCs via the inhalation exposure route when breakthrough of the activated carbon bed occurs. Breakthrough may result in high VOC concentrations in the exhaust.

Control: Controls for VOC exposure include

- Monitor effluent periodically to determine when breakthrough occurs.
- Replace or regenerate carbon on a regular schedule.
- Train workers in potential chemical exposure hazards and controls (see 29 CFR 1910.1200).

CONTROL POINT: Operations, Maintenance

(3) Chemical Exposure.
Description: Activated carbon can corrode carbon steel in tanks and piping, which may cause leaks and worker exposure to chemicals.

Control: Controls for chemical exposure include

- Do not use carbon steel to contain activated carbon. Use stainless steel, thermoplastic, or other chemically-resistant tank materials.
- Paint, coat, or line tank interiors to prevent contact between activated carbon and carbon steel.
- Train workers in potential chemical exposure hazards and controls (see 29 CFR 1910.1200).

CONTROL POINT: Design, Construction, Maintenance

(4) VOC Exposure (Saturated Carbon).
Description: During removal of saturated carbon, worker exposure to VOCs may occur.

Control: Controls for VOC exposure include

- Monitor worker exposure to VOCs during carbon removal.
- Use respiratory protection appropriate for VOCs present (e.g., air-purifying respirator equipped with organic vapor cartridges) if worker exposure levels exceed permissible exposure levels (PELs).

CONTROL POINT: Operations, Maintenance

c. Radiological Hazards.

No unique hazards are identified.

d. Biological Hazards.

No unique hazards are identified.

Chapter 21
Ion Exchange (Liquid/Vapor)/Resin Adsorption (Liquid/Vapor

21.1. General.

The processes of ion exchange and resin adsorption are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

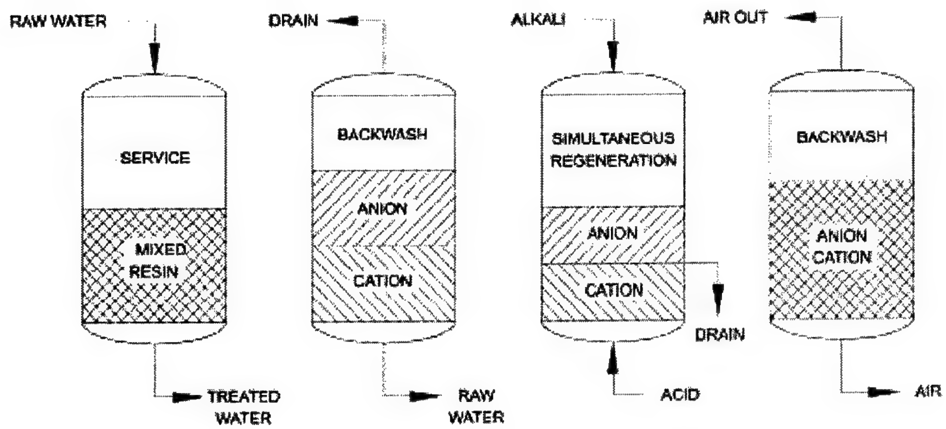
21-2. Technology Description.

a. Ion Exchange.

Ion exchange technology uses resins (solid or semi-solid organic materials that do not conduct electricity) or polymers with numerous reversibly reactive side groups to remove ions such as heavy metals from liquid or gaseous streams. The removal occurs by exchange of cations or anions between the contaminated water/gas and the ion exchange medium, based on the differential binding activities of the two exchanged ions. In practice, gaseous streams are usually treated by passage over wet ion exchange resin. The contaminants are trapped in the water and exchange with the resin's leaving ion. Generally, heavy metal ions (copper, lead, calcium, and others) will bind more tightly to the ion exchange resin than lighter metals (sodium, potassium). Ion exchange materials contain ionic functional groups to which exchangeable ions are attached. In the presence of the stronger binding ion, the weaker binding ion will eventually be displaced. After most of the resin capacity has been exchanged, resins can be regenerated for reuse using acids or bases, and/or solutions of weakly binding ions. During the regeneration process, a concentrated heavy metal stream is eluted for disposal. Figure 21-1 illustrates both ion exchange (liquid/vapor) and resin adsorption (liquid/vapor).

b. Resin Adsorption.

Resin adsorption removes undesirable ions from water on the same chemical basis, except that the resin is not exchanged with another metal ion such as sodium or potassium, but is exchanged with the appropriate proton or hydroxyl group. Regeneration is by elution of the heavy metals with acid or base to regenerate the resin by reversing the exchange.



PRINCIPLE OF MIXED-BED ION EXCHANGE: (A) SERVICE PERIOD. (B) BACKWASH PERIOD. (C) SIMULTANEOUS REGENERATION. (ILLINOIS WATER TREATMENT CO.)

SOURCE: *CHEMICAL ENGINEER'S HANDBOOK*, PERRY & CHILTON (5TH. EDITION)

FIGURE 21-1. ION EXCHANGE/RESIN ADSORPTION

21-3. Hazard Analysis.

Principal unique hazards associated with ion exchange (liquid/vapor)/resin adsorption (liquid/vapor), methods for control, and control points are described below

a. Physical Hazards.

(1) Electrocution.
Description: Workers may be exposed to electrical hazards when working around resin beds. If permanent and temporary electrical equipment that is not ground-fault protected contacts water or other liquids, an electrocution hazard exists.

Control: Controls for electrocution include

- Verify that drawings indicate the hazardous area classifications as defined in NFPA 70-500-1 through 500-10.

- Use controls, wiring, and equipment with adequate ground-fault protection that meet the requirements of EM 385-1-1, Section 11.G; NFPA 70; and CEGS 16415: Electrical Work, Interior for the identified hazard areas.

CONTROL POINT: Design, Construction, Operations, Maintenance

(2) Liquid Transfer Equipment Design.
Description: Improperly selected construction materials, such as untreated steel, can corrode or dissolve to a point of failure and cause damage to the facilities or expose workers to crushing hazards associated with falling or collapsing equipment.

Control: Controls for liquid transfer equipment include
- Use liquid transfer equipment (pumps, fan, blowers, piping, pipe fittings, valves, and instruments) fabricated from materials that are chemically resistant to the liquid streams.
- Consult Hydraulic Institute standards HI 9.1-9.5 for appropriate pumping materials. Chemical resistance charts are available through the National Association of Corrosion Engineers (NACE).

CONTROL POINT: Design, Construction, Maintenance

(3) Pressurized System Failure.
Description: Ion exchange systems consist of pressurized beds (e.g., tanks, pumps, and piping). Pressurized systems can leak or fail, causing exposure to the contaminated influent stream and/or backwash or reconditioning chemicals.

Control: Controls for pressurized system failure include
- Design tanks and piping for the maximum operating pressure expected.
- Hydro test all systems in accordance with CEGS 11250—Water Softeners, Cation-Exchange (Sodium Cycle)—before the system is put into operation.
- Include containment drip pans or receivers where leaks may occur.
- Prevent the commingling of chemicals.
- Install spill and/or leak detection instruments if necessary.
- Implement routine system operation inspection.

CONTROL POINT: Design, Construction, Operations

(4) Backwash System Failure.
Description: Some systems have automatic backwash cycles during which the resin is regenerated by flushing with an acid or base. Failure of these automated backwash systems may expose workers to possible physical hazards associated with a disrupted process or to a chemical exposure.

Control: Controls for backwash system failure include
- Design backwash automatic controls into the system.

- Include back-up control logic to alarm and shut down systems if primary controls fail to shut down the system.
- Train workers in potential acid/base exposure hazards and controls (see 29 CFR 1910.1200).

CONTROL POINT: Design, Operations, Maintenance

(5) Fire or Explosion (VOCs).
Description: Workers may be exposed to a fire or explosion hazard if, during regeneration of the resin, the heat of the reaction is sufficient to ignite VOCs that may have accumulated within the vessel.

Control: Controls for fire or explosion in vapor-phase systems include
- Sweep or purge the vessel's atmosphere with inert gas prior to, and/or during, the regeneration phase to help prevent an explosion or fire.

CONTROL POINT: Design, Operations, Maintenance

(6) Explosion.
Description: Workers may be exposed to an explosion hazard during the mixing of incompatible chemicals. The resulting reaction may generate heat and pressure buildup causing an explosion.

Control: A control for explosion includes
- Design the system with process controls that shut down the system during over-pressurization. These controls may include emergency warning alarms and pressure-relief valves and vents that discharge away from the work area.

CONTROL POINT: Design

(7) Treatment Buildings.
Description: Permanent or semi-permanent treatment buildings may present life safety hazards such as inadequate egress, fire suppression systems, and/or emergency lighting systems.

Control: Controls for treatment buildings include
- Meet the following construction requirements for permanent and semi-permanent treatment buildings: ANSI 58.1: Minimum Design Loads for Buildings and other Structures; the National Fire Code; the National Standard Plumbing Code; Life Safety Code; and the Uniform Building Code.
- Make sure structures comply with either the Air Force Manuals on Air Force bases, the USACE Technical Manuals on Army installations, or local building codes on Superfund, BRAC, or FUDS project sites.

CONTROL POINT: Design, Operations

(8) Emergency Wash Equipment.

Description: Emergency shower/eye wash equipment required per 19 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards or walking surface hazards during required testing/use.

Control: A control for emergency wash equipment includes

- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping hazards.

CONTROL POINT: Design

(9) Fire (Flammable Materials).
Description: Ion exchange resins are generally fabricated from flammable materials that can be ignited under certain operating and storage conditions.

Control: A control for fire includes

- Consult and adhere to the appropriate resin Material Safety Data Sheets (MSDS) and resin manufacturers' recommendations regarding proper resin use and storage.

CONTROL POINT: Design, Construction, Operations

(10) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Deteriorating or Incompatible Chemicals.
Description: Resins (solid or semi-solid organic materials) used in ion exchange treatment technologies may have specific storage requirements regarding heat and moisture content and may deteriorate, producing potentially hazardous conditions (such as acidic conditions). Acids (sulfuric and hydrochloric) and bases (such as sodium hydroxide) used during backwash or

regeneration are incompatible with each other and should be stored separately or separated in the containment area. Inadequately contained reagents or spills of incompatible reagents in common storage areas may generate fumes or cause fires.

Control: Controls for deteriorating or incompatible chemicals include

- Store resins according to MSDS requirements.
- Do not store more resin than can be used within the acceptable storage period.
- Store incompatible materials, such as acids and caustics, separately or in individual secondary containment.
- Design storage systems based on incompatibilities using known process chemistry and MSDS information. Design facilities that keep incompatible chemicals isolated from each other.
- Equip each chemical storage tank or drum with adequate spill containment.
- Install spill and/or leak detection instruments if necessary.
- Require proper loading and chemical handling procedures.
- Handle the backwash liquids with the same operational procedures as the process liquids.

CONTROL POINT: Design, Operations, Maintenance

(2) Chemical Reagent and Resin Handling.
Description: Workers may be exposed via the inhalation/ingestion/dermal exposure routes when adding chemical reagents and resins to the system. The chemical reagents may include sulfuric and hydrochloric acid. This activity may occur either at the initial loading of the materials or during the regeneration stage. The resulting exposure may cause burns, irritation, or more severe tissue damage.

Control: Controls for reagent and resin handling include

- Handle chemical reagents and resins under ventilated conditions.
- Use appropriate personal protective equipment (PPE) such as an air-purifying respirator with acid gas cartridges and butyl rubber gloves.
- Locate an eye wash/chemical spill shower close to the chemical handling areas.
- Train workers in potential chemical exposures to expect and the associated controls (see 29 CFR 1910.1200).

CONTROL POINT: Design, Operations, Maintenance

(3) Backwash Fluid Solution.
Description: Eludation of the captured heavy metals from the resin bed will produce a filtrate solution that contains elevated concentrations of the heavy metals in an acidic or basic solution.

Control: A control for backwash fluid solution includes

- Handle the backwash fluid solution with the same procedures and protocols as those used for process fluids (e.g., proper containment precautions and observing all personal safety measures when handling the fluid material).

CONTROL POINT: Operations, Maintenance

c. Radiological Hazards.

Radioactive Contaminants.
Description: Because the ion exchange treatment technology may remove radionuclides from aqueous waste solutions, the potential exists for worker exposure to radionuclides during treatment of radioactive wastes. In some geological settings, dissolved naturally occurring radioactive materials (NORM) or radioactive contaminants may be drawn up with the groundwater. Depending on the chemical form, the radioactive contaminant may be trapped by the ion exchange resin and concentrated to a point where a radiation hazard may develop.

Control: Controls for radioactive contaminants include

- Test the contents of the waste stream.
- Determine the nature and extent of the radiation and/or radioactive materials if present.
- Consult a qualified health physicist to determine the exposure potential and any necessary engineering controls or PPE if radioactive material exceeds background levels.

CONTROL POINT: Maintenance

d. Biological Hazards.

No unique hazards are identified.

Chapter 22
Low-Temperature/High-Temperature Thermal Desorption

22-1. General.

The processes, applications, and limitations of low-/high-temperature thermal desorption are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

22-2. Technology Description.

a. Process.

Low-temperature and high-temperature thermal desorption treat wastes by distilling (evaporating) water and organic compounds from the feed solids such as soils (see Figure 22-1). These processes are physical separation methods and are not designed to directly destroy organic compounds. Consequently, these processes can operate at lower temperatures than incineration. In practice, the off gas laden with the evaporated contaminants is often incinerated in higher temperature, smaller, and more economical secondary burner/incinerators. However, the off-gas contaminants can also be condensed for disposal or reuse. The terms low- and high-temperature thermal desorption are somewhat arbitrary classifications, since most units can operate across a range of temperatures, and the high- and low-range systems overlap considerably in capability. Oxidation is controlled by adjusting the bed temperatures and residence times in the system.

Excavated soil or solids are homogenized and oversized rejects are removed prior to feeding the soil into the desorption system. Two common thermal desorption systems are the rotary dryer and thermal screw. Rotary dryers are horizontal cylinders that are inclined and rotated during firing. Thermal screw units utilize screw conveyors or hollow augers to transport the medium through an enclosed trough. Hot oil or steam circulates through the auger to indirectly heat the medium. Particulates generated during desorption are removed by wet scrubbers or baghouse (fabric) filters. Volatile contaminants are purged with a carrier gas or vacuum system and are removed through condensation followed by carbon adsorption, or they are destroyed in a secondary combustion chamber or catalytic oxidizer. The treated medium is returned to the excavation after testing.

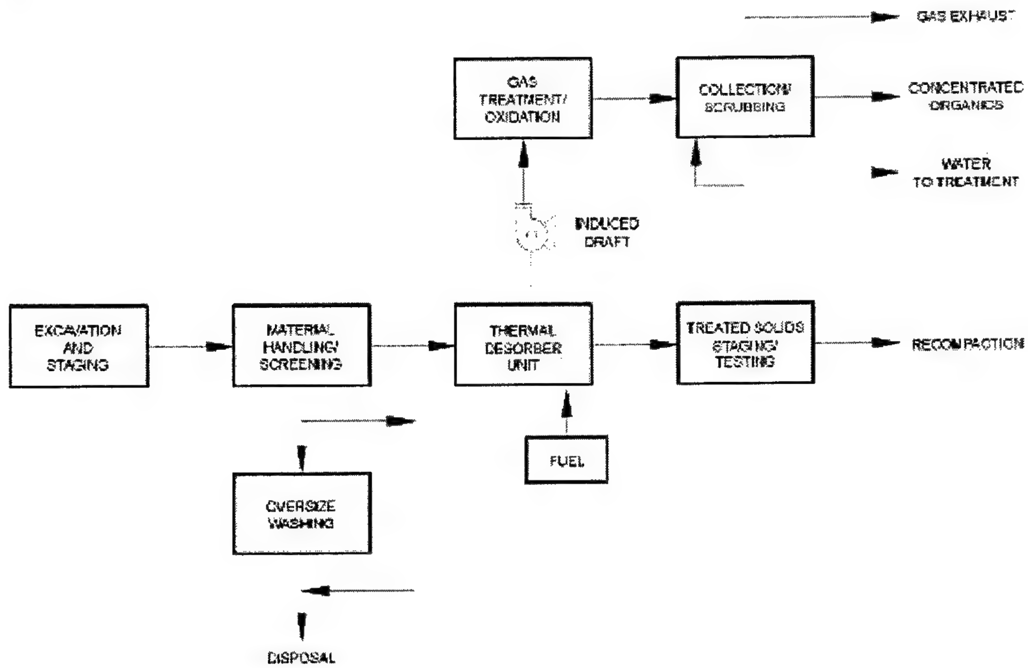


FIGURE 22-1. TYPICAL PROCESS FLOW FOR LOW-TEMPERATURE/ HIGH-TEMPERATURE THERMAL DESORPTION

b. Applications.

Low-temperature thermal desorption systems are effective for the removal of nonhalogenated and halogenated volatile organic compounds (VOCs) and petroleum hydrocarbons. Semi-volatile organic compounds (SVOCs) can be treated with reduced effectiveness. Soil decontaminated with a low-temperature thermal desorption system retains its physical properties.

High-temperature thermal desorption systems are effective for the removal of VOCs, SVOCs, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, coal tar wastes, creosote-contaminated soils, paint wastes, and mixed (radioactive and hazardous) wastes. Volatile metals may be removed by high-temperature thermal desorption systems. Soils treated with high-temperature thermal desorption may lose many of their soil properties and may need to be amended if expected to provide structure. Systems for both technologies are available as transportable units that can be mobilized to sites.

c. Limitations.

Limitations are similar in both systems. Dewatering of the feed soils may be required to reduce the amount of energy required to heat the soil in both the low- and high-temperature thermal desorption systems. Clay and silt-based soils or high humic content soils may increase the required residence times due to binding of organic constituents. Heavy metals in the soil may produce a residue that requires stabilization prior to returning it to the excavation. Feed particle size limitations can impact applicability and cost for specific soil types, and abrasive feed streams may damage the processor unit.

22-3. Hazard Analysis.

Principal unique hazards associated with low-temperature/high-temperature thermal desorption, methods for control, and control points are described below

a. Physical Hazards.

(1) Noise Hazards.
Description: Desorption treatment units may expose workers to elevated noise levels in the work area due to the operation of air blowers, pumps, and the ignition of fuels within the combustion chamber. The noise level may interfere with safe and effective communications.

Control: Controls for noise hazards include

- Follow the regulatory requirements of CEGS 02289 (Remediation of Contaminated Soils by Thermal Desorption).
- Use hearing protection and establish a hearing protection program (see 29 CFR 1910.95).
- Use personal electronic communications devices, such as a dual ear headset with speaker microphone, to overcome ambient noise. The device reduces ambient noise levels while enhancing communication.
- Establish noise-free areas during operations to provide breaks from the noise, which can cause fatigue and inattention.

CONTROL POINT: Design, Operations

(2) Fire or Explosion (High Operating Temperatures).
Description: Thermal desorption units that are not operated below the ASTM E953-determined ash fusion temperature may cause the solid waste material to vitrify into a large, hot mass within the unit. The resulting heat and pressure buildup may exceed the equipment pressure rating of the unit, possibly causing a fire or explosion or release of the vitrified waste materials during operation or maintenance.

Control: Controls for fire and explosion include

- Operate the unit following the instructions in CEGS 02289, Remediation of Contaminated Soils by Thermal Desorption. This standard, in part, requires:
    - A Startup Plan.
    - A Proof of Performance Plan listing the proposed operating conditions for process parameters to be continuously monitored and recorded.
    - An Operating Plan specifiying detailed procedures for continued operation of the system, based on the proof of performance results.
    - A Demobilization Plan.

CONTROL POINT: Design, Operations, Maintenance

(3) Flammable/Combustible Fuels.
Description: Thermal desorption usually requires storage of flammable or combustible fuels (e.g., kerosene, waste fuels). Hazards associated with flammable/combustible fuels include the potential for on-site spills or release of material. The release may cause worker exposure to the vapors generated, or a fire hazard may exist if the material is ignited.

Control: Controls for flammable/combustible fuels include

- Use appropriate tanks, equipped with pressure-relief devices and bermed to help prevent release of material.
- Use electrical equipment and fixtures that comply with NFPA 70.
- Follow CEGS 02289 (Remediation of Contaminated Soils by Thermal Desorption). It requires that fuel system installation/storage/testing comply with: NFPA 30 (Flammable and Combustible Liquids Code); NFPA 31 (Installation of Oil Burning Equipment); NFPA 54 (National Fuel Gas Code); or NFPA 58 (Standard for the Storage and Handling of Liquefied Petroleum Gases).
- Ventilate the area adequately to help prevent the accumulation of flammable vapors.
- Permit only trained and experienced workers to work on the system.
- Use lock-out and tag-out procedures on all electrical systems during repair or maintenance.

CONTROL POINT: Design, Construction, Operations, Maintenance

(4) Ignition of Saturated Soils.
Description: During excavation of waste materials with low flash points, saturated soils may be ignited by sparks generated when the blade of the dozer or crawler contacts rocks or other objects under unusual or extraordinary conditions. If the soil will be crushed prior to feeding into the desorption unit, waste materials with higher than expected BTU values may ignite during the crushing/sorting process.

Control: Controls for ignition of saturated soils include

- Apply water periodically to the soils (before and during crushing).
- Equip soil-handling equipment with non-sparking buckets or blades.

CONTROL POINT: Operations

(5) Fire or Explosion (High-BTU Feed).
Description: If the BTU value of the waste feed is not controlled and high-BTU feed enters the desorption unit, the temperature of the unit may exceed design specifications, possibly resulting in fire or explosion.

Control: Controls for fire include

- Use experienced operators and supervisors.
- Audit and apply proper QA/QC to assure that the unit is operating according to design and that the waste feed has a consistent BTU value based on design parameters.

CONTROL POINT: Design, Operations

(6) Electrocution.
Description: Since desorption treatment units operate electrical systems outdoors, workers may be exposed to electrocution hazards if the electrical equipment comes in contact with water.

Control: Controls for electrocution include

- Verify that drawings indicate the hazardous area classifications as defined in NFPA 70-500-1 through 500-10.
- Use controls, wiring, and equipment with adequate ground-fault protection that meet the requirements of EM 385-1-1, Section 11.G; and NFPA 70.
- Use adequate ground-fault protection.

CONTROL POINT: Design, Construction, Operations, Maintenance

(7) Transfer Equipment Design.
Description: All transfer equipment (conveyors, piping, process units, and instruments) in contact with contaminated materials should be fabricated from materials that are chemically resistant to the given contaminant chemical. Improperly designed systems can corrode or dissolve, causing damage to the facilities or exposing workers to collapse hazards from falling equipment.

Control: Controls for transfer equipment include

- Use equipment fabricated from materials that are chemically resistant to contaminants in the system.
- Chemical resistance charts are available through the National Association of Corrosion Engineers (NACE).
- Install spill and/or leak detection instruments if necessary.

- Include containment drip pans or receivers where liquids may separate from solid materials.

- CONTROL POINT: Design, Construction, Maintenance

(8) Burn Hazards.
Description: The thermal desorption process may use high temperatures to heat materials. The materials that are processed will exit the system hot, exposing workers to possible thermal burn hazards.

Control: Controls for burns include
- Use temperature safety control systems to protect people and equipment.
- Post signs warning of high temperatures.
- Use safety barriers to isolate critical sections of the equipment.
- Design systems to handle the materials exiting the system. Follow NFPA 30, 31, and 54 and CEGS 02289 (Remediation of Contaminated Soils by Thermal Desorption) criteria.
- Use heat resistant gloves to help prevent thermal burns.

CONTROL POINT: Design, Operations, Maintenance

(9) Transfer Systems.
Description: Transfer systems such as screw conveyors or augers expose workers to injury if limbs or clothing are caught in the system.

Control: Controls for transfer systems include
- Enclose transfer systems to the maximum extent possible.
- Install emergency shutoff controls in multiple locations.
- Enforce lock-out/tag-out procedures rigorously.
- Train workers in identification of pinch points in the system.

CONTROL POINT: Design, Operations, Maintenance

(10) Respirable Quartz.
Description: Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422, followed by analysis of the fines by X-ray diffraction to determine fine material quartz content.

Control: Controls for respirable quartz include
- Wet the soil periodically with water or amended water to minimize worker exposure.
- Use respiratory protection, such as an air-purifying respirator equipped with a HEPA (N100, R100, P100) filter.

CONTROL POINT: Construction, Operations

(11) UV Radiation.
Description: During site activities, workers may be exposed to direct and indirect sunlight and the corresponding UV radiation. Even short-term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control: Controls for UV radiation include
- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen.
- Shade work and break areas, if possible.
- Minimize exposure to heat stress conditions by taking frequent breaks, drinking adequate fluids, and performing work during the early morning and late afternoon hours.

CONTROL POINT: Construction, Operations

(12) Electrocution Hazards.
Description: Workers may be exposed to electrocution hazards when working around electrical utilities such as overhead power lines.

Control: Controls for electrocution include
- Verify the location of overhead power lines, either existing or proposed in the pre-design phase through contacting local utilities.
- Keep all lifting equipment at least 10 feet from the power line according to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1926.550 and EM 385-1-1, Section 11.E.

CONTROL POINT: Design, Construction, Operations

(13) Traffic Hazards.
Description: During the implementation of field activities, equipment and workers may come in close proximity to traffic. Also, equipment may need to travel or cross public roads. The general public may be exposed to traffic hazards and the potential for accidents.

Control: Controls for traffic hazards include
- Post warning signs according to the criteria of the Department of Transportation Manual on Uniform Traffic Devices for Streets and Highways.
- Develop a traffic management plan before remediation activities begin to help prevent accidents involving site equipment. EM 385-1-1, Section 21.I10 provides plan details.

CONTROL POINT: Design, Construction, Operations

(14) Heated Surfaces.
Description: Workers may be exposed to infrared radiation hazards associated with working in the vicinity of thermal desorbing treatment units. The exposure, depending on the temperature of the equipment, length of exposure, and other variables may increase the risk of cataracts.

Control: Controls for heated surfaces include
- Minimize worker exposure to heated equipment surfaces.
- Use eye protection with the appropriate shade safety glass if prolonged work is required.

CONTROL POINT: Operations, Maintenance

(15) Confined Spaces.
Description: Workers may be exposed to confined-space hazards during entry into the process equipment for repair, inspection, or maintenance activities. Confined-space hazards may include injury by release of hot, vitrified waste material; exposure via the inhalation route to toxic materials (e.g., vinyl chloride); and/or exposure to an oxygen-deficient atmosphere or entanglement.

Control: Controls for confined spaces include
- Test the atmosphere within the confined space prior to entry (see 29 CFR 1910.146).
- Design air-handling systems to minimize or eliminate oxygen-deficient locations.
- Use air-supplied respirators to help control inhalation exposures to toxic chemicals (e.g., vinyl chloride) or to help prevent asphyxiation.
- Allow process equipment to cool completely and thoroughly inspect to identify build-up of vitrified waste material within equipment prior to entry.

CONTROL POINT: Operations, Maintenance

(16) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include
- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Waste Material Exposure (Excavation and Transport).
Description: Worker exposure to waste materials may occur during excavation and transport of waste materials. Dry soils may generate airborne dusts contaminated with toxic materials (e.g., respirable silica, metals, semi-volatile organics, pesticides, etc.).

Control: Controls for waste material exposure include

- Wet dust periodically to prevent airborne dust generation.
- Use respiratory protective equipment such as an air-purifying respirator with approved filter/cartridges like HEPA (N100, R100, P100) for particulates; OV cartridges for vapors; or combination filter/cartridges for dual protection.

CONTROL POINT: Operations

(2) Waste Byproducts.
Description: During operation of the desorption unit, workers may be exposed to byproducts of incomplete combustion such as carbon monoxide or to airborne toxic materials, including metal acetates, mercury, and chlorine.

Control: Controls for waste byproducts include

- Classify wastes prior to desorption. Feed only those waste materials compatible with the process into the unit.
- Design the process and off-gas treatment to control generation and release of toxic materials.
- Use necessary PPE such as an air-purifying respirator equipped with HEPA (N100, R100, P100) filters appropriate for the contaminants of concern and air emissions controls if necessary.

CONTROL POINT: Design, Operations

(3) Waste Material Exposure (Desorption Unit).
Description: During maintenance of the desorption unit, workers entering the unit for cleaning, inspection, or repair of equipment may be exposed to waste materials or incomplete combustion byproducts (e.g., metal acetates, mercury, chlorine, etc.). In addition, workers may be exposed to toxic vapors or an oxygen-deficient atmosphere by entering into confined space.

Control: Controls for waste material exposure include

- Use confined-space entry procedures if appropriate (see 29 CFR 1910.146).
- Assess the hazard exposure at the time of entry.
- Wear appropriate PPE.

- Design the facility and unit for ease of cleaning and maintenance to minimize the frequency, duration, and extent of exposure.

CONTROL POINT: Design, Maintenance

(4) Exhaust Vapors.
Description: Workers may be exposed via the inhalation exposure route during the thermal desorption process. Since some chemical contaminants, such as fuel oils, are not completely destroyed in the process, they may be discharged via the exhaust stack into the work area.

Control: Controls for exhaust vapors include
- Gather exhaust vapors for further processing in an off-gas treatment unit (e.g., vapor carbon beds, incinerators, thermal oxidizers, or gas scrubbing towers). Fugitive emissions are possible if systems are not designed to address these issues.
- Do not operate systems at less than atmospheric pressures to eliminate fugitive emissions problems.

CONTROL POINT: Design, Operations

(5) Toxic Dust.
Description: If the soil or materials being treated are rich in silica-based materials such as quartz, worker exposure to crystalline silica dust may occur. Soils composed of silt and clays are likely to create atmospheres with high respirable dust concentrations.

Control: Controls for toxic dust include
- Keep feed material and ash slightly moist to suppress dust.
- Perform adequate maintenance and seal all leaks in the thermal treatment system to reduce the generation of emitted silica or other dust.
- Consult geotechnical staff to determine if site-specific soils are rich in quartz particles.
- Provide air-purifying respirators with HEPA (N100, R100, P100) filters at a minimum.

CONTROL POINT: Operations, Maintenance

c. Radiological Hazards

Unique radiological hazards are typically not associated with this technology. Consult with a certified health physicist if mixed or radioactive waste is being treated to identify potential radiological hazards during design.

d. Biological Hazards.

No unique hazards are identified.

Chapter 23
Incineration

23-1. General.

The process and applications of incineration are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

23-2. Technology Description.

a. Process.

Incineration is a treatment process for contaminated soil, sludges, sediments, and liquids using combustion to oxidize organic materials. Oxidation is effected by extreme heat (incineration of vapor streams is discussed in Chapter 24). Materials are heated to a specified temperature (usually at least 1800° F) for a specified time (usually at least 1 second at temperature) to oxidize the contaminants. The appropriate temperature and residence time is dependent on the nature of the waste stream and contaminants. The energy for the oxidation is provided by a gaseous or liquid fuel fired in the incinerator. In some cases the material to be oxidized supplies some of the heating value, and the fuel cost can be reduced. Oxygen is supplied from air and/or pure oxygen feeds. The products of combustion are carbon dioxide, water, and depending on the feed, acid gases, metal oxides, and noncombustible ash.

While the basic process is simple and reliable, there are very stringent requirements for treating the vapor emissions from the incinerator that add greatly to the expense. Particulates, ash, and incomplete combustion products (carbon monoxide and hydrocarbons) must be removed from the exhaust prior to discharge. The ash usually requires handling and disposal as a hazardous waste material and is sent to special landfills for this purpose. The particulates are removed using either baghouses or electrostatic precipitators, and the dust is usually handled in the same fashion as the ash. In addition, acid gases that form when oxidizing halogenated compounds must be removed in acid gas scrubbers. These acid gases can cause serious physical damage to workers and equipment if left uncontrolled. The water stream generated by the scrubber is a dilute acid, which must be disposed of properly. See Figure 23-1.

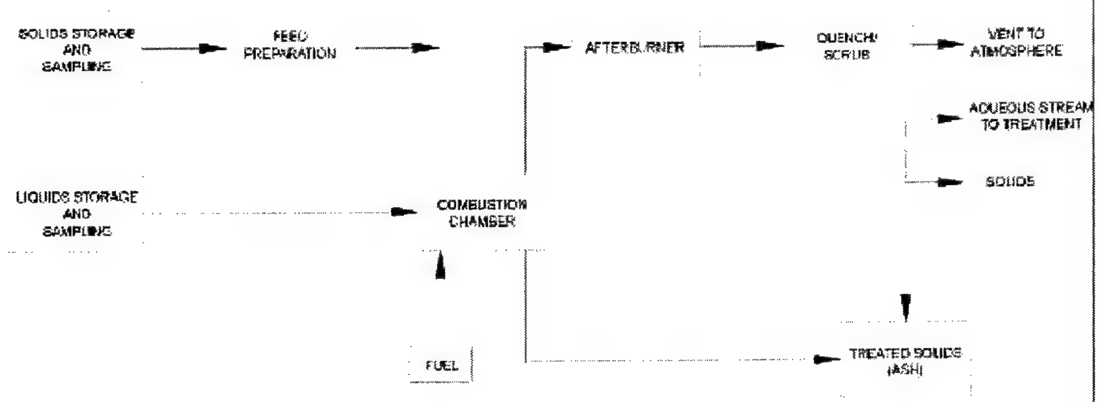


FIGURE 23-1. TYPICAL PROCESS FLOW FOR INCINERATION

b. Applications.

The incineration process is applicable to a wide range of waste streams, including volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), pesticides, solvents, polychlorinated biphenyls (PCBs), virtually all fuel and tar streams, and combinations of these compounds. It is very effective in terms of percent destruction of the compounds of concern. The feed to the incinerator is usually a liquid or a solid (or a combination). Sludges, semi-solids, and cakes may be effectively treated, provided the feed handling system can convey these materials to the unit. Oversized solids (rocks, large chunks) may be removed by screening devices before the material is fed into the combustion chamber.

23.3 Hazard Analysis.

Principal unique hazards associated with incineration, methods for control, and control points are described below

a. Physical Hazards.

(1) Noise Hazards.
Description: Incinerators may cause elevated noise levels in the work area due to the operation of air blowers, pumps, and the ignition of fuels within the combustion chamber. The noise level may interfere with safe and effective communications.

Control: Controls for noise hazards include
- Refer to CEGS 02288 (Remediation of Contaminated Soils and Sludges by Incineration) for noise control.
- Use hearing protection.
- Use personal electronic communications devices, such as a dual ear headset with speaker microphone, to overcome ambient noise.
- Establish noise-free areas during operations to provide breaks from the noise, which can cause fatigue and inattention.

CONTROL POINT: Design, Operations

(2) Heat and Pressure Buildup.
Description: Incinerators with rotary kilns that are improperly operated may cause the solid waste material to vitrify into a large, hot mass within the unit. The resulting heat and pressure buildup may exceed design specifications of the unit, potentially causing damage to the unit and release of waste materials. Vitrified material may fall on workers entering the unit during maintenance.

Control: Controls for heat and pressure buildup include
- Follow operating instructions in CEGS 02288, Remediation of Contaminated Soils and Sludges by Incineration. Section 1.2.2.3 of the standard addresses slagging control requirements. The standard also requires the following plans:
  - A Mobilization Plan.
  - A Startup Plan describing in detail control system functions, specific procedures proposed to demonstrate each function, and how to test the system with uncontaminated materials.
  - A Trial Burn Plan listing the proposed operating conditions to be continuously monitored and recorded.
  - A Demobilization Plan.
- Operate the unit within the design and control parameters.
- Audit operations periodically and review for excursions from standards.
- Design controls that prevent unit entry until all material has cooled.

CONTROL POINT: Design, Operations, Maintenance

(3) Flammable/Combustible Fuels.
Description: Incinerators usually require storage of flammable or combustible fuels (e.g., kerosene, waste fuels). Hazards associated with flammable/combustible fuels include the potential for an on-site spill or release of material. The release may cause worker exposure to the vapors generated, or a fire hazard may exist if the material is ignited.

Control: Controls for flammable/combustible fuels include

- Meet mandatory requirements of NFPA 30 (Flammable and Combustible Liquids Code); NFPA 31 (Installation of Oil Burning Equipment); NFPA 54 (National Fuel Gas Code); or NFPA 58 (Standard for the Storage and Handling of Liquefied Petroleum Gases) for fuel system installation, storage, and testing.

CONTROL POINT: Design, Operations, Maintenance

(4) Ignition of Saturated Soils.
Description: During excavation of waste materials with low flash points, saturated soils may be ignited by sparks generated when the blade of the dozer or crawler contacts rocks or other objects under unusual or extraordinary conditions. If the soil will be crushed prior to feeding into the incinerator, waste materials with high BTU values may ignite during the crushing/sorting process.

Control: Controls for ignition of saturated soils include

- Apply water periodically to the soil (before and during crushing).
- Equip soil-handling tools with non-sparking buckets or blades.

CONTROL POINT: Operations

(5) Electrocution.
Description: Since incinerators operate electrical systems outdoors, workers may be exposed to electrocution hazards.

Control: Controls for electrocution include

- Verify that drawings indicate the hazardous area classifications as defined in NFPA 70-500-1 through 500-10.
- Use controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11.G; NFPA 70.
- Use adequate ground-fault protection.

CONTROL POINT: Design, Construction, Operations, Maintenance

(6) Incinerator Operation.
Description: Workers may be exposed to waste chemicals via the inhalation exposure route if high-BTU waste material is fed into the incinerator at a rate that exceeds its design parameter. The heat and force generated may overpressure the system, resulting in a release of waste chemical vapors into the work area.

Control: Controls for incinerator operation include
- Use experienced operators and supervisors.
- Audit and apply proper QA/QC to assure work is done as designed.
- Operate the system and waste material within design parameters.

CONTROL POINT: Design, Operations

(7) Incineration System Design.
Description: The incineration process can use one piece of equipment with two or more additional waste processing units attached. Most waste incinerators include equipment similar to thermal desorption units for handling materials at the inlet and exit of the unit. Accordingly, there may be off-gas conditioning equipment similar to vapor scrubbers or catalytic converters added to incinerators. Each piece of equipment has its own hazards. The basic design requirements for incinerators are regulated by the Environmental Protection Agency (EPA). These design requirements are specified to eliminate releases of contaminants that cause related personnel exposure.

Control: Controls for the incineration system include
- Include hazard control to support all the individual systems included in the system.
- Design the incineration process according to EPA requirements. Design requirements should meet CEGS 02288: Remediation of Contaminated Soils and Sludges by Incineration.

CONTROL POINT: Design

(8) Transfer Equipment Design.
Description: Improperly designed systems can corrode or dissolve to a point of failure and cause damage to the facilities or exposure to workers.

Control: Controls for transfer equipment design include
- Use equipment fabricated from materials that are chemically-resistant to the chemical being transferred. Chemical resistance charts are available through the National Association of Corrosion Engineers (NACE).
- Install spill and/or leak detection instruments including alarms if necessary.
- Include containment drip pans or receivers where leaks may occur.

CONTROL POINT: Design, Construction, Maintenance

(9) Burn Hazards.
Description: Workers may be exposed to burn hazards to the skin from hot ash during operation and clean out of the incinerator.

Control: Controls for burn hazards include
- Use temperature safety control systems to protect people and equipment.
- Design the system to handle materials exiting the system.
- Install safety barriers to isolate critical sections of the equipment.
- Post signs warning of high temperatures.
- Permit worker maintenance only after process equipment has cooled.

CONTROL POINT: Design, Operations, Maintenance

(10) Transfer Systems.
Description: Transfer systems such as feed belts, augers, conveyors, etc., expose workers to injury if limbs or clothing are caught in the system.

Control: Controls for transfer systems include
- Enclose transfer systems to the maximum extent possible.
- Install emergency shutoff controls in multiple locations.
- Enforce lock-out/tag-out procedures rigorously.
- Train workers to identify pinch points in the system.

CONTROL POINT: Design, Operations, Maintenance

(11) Heated Surfaces.
Description: Workers may be exposed to infrared radiation hazards associated with working in the vicinity of incinerators. The exposure, depending on the temperature of the equipment, length of exposure, and other variables may increase the risk of cataracts.

Control: Controls for heated surfaces include
- Minimize worker exposure to heated equipment surfaces.
- Use eye protection with the appropriate shade safety glass to control eye exposure.

CONTROL POINT: Operations, Maintenance

(12) Respirable Quartz.
Description: Depending on soil types, exposure to respirable quartz may be a hazard. Consult geology staff to confirm the presence of a respirable quartz hazard (e.g., to determine if soil types are likely to be rich in respirable quartz). As an aid in determining respirable quartz exposure potential, sample and analyze site soils for fines content by ASTM D422, followed by analysis of the fines by X-ray diffraction to determine fine material quartz content.

Control: Controls for respirable quartz include

- Wet the soil periodically with water or amended water to minimize worker exposure.
- Use respiratory protection such as an air-purifying respirator equipped with a HEPA (N100, R100, P100) filter.

CONTROL POINT: Operations, Maintenance

(13) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Waste Material Exposure (Excavation and Transport).
Description: Worker exposure may occur during excavation and transport of waste materials. Dry soils may generate airborne dusts contaminated with toxic materials.

Control: Controls for waste material exposure include

- Wet dust periodically to prevent airborne dust generation.
- Use respiratory PPE such as an air-purifying respirator with approved filter/cartridges such as HEPA (N100, R100, P100) filters for particulates; OV cartridges for vapors; or combination filter/cartridges for dual protection.

CONTROL POINT: Operations

(2) Incinerator Entry.
Description: During maintenance of the incinerator, workers entering the unit for cleaning, inspection, or repair of equipment may be exposed to waste materials or incomplete combustion byproducts, such as chlorine and carbon monoxide.

Control: Controls for exposure to waste materials during incineration maintenance include

- Adhere to confined-space entry protocols that address air testing prior to entry (see 29 CFR 1910.146).
- Meet PPE requirements, including an air-purifying/air-supplying respirator with organic vapor cartridges and water/chemical impervious gloves.
- Allow equipment to cool completely and thoroughly inspect for build-up of waste materials prior to entry.

CONTROL POINT: Operations

(3) Toxic Material Exposure (Feed or Byproducts).
Description: During operation of the incinerator, workers may be exposed to waste components/toxic materials in the feed; byproducts of incomplete combustion, such as carbon monoxide; or to airborne toxic materials, including metal acetates, mercury, and chlorine. In addition, toxic byproducts, such as dibenzofurans and dioxins, may also be generated during the process.

Control: Controls for exposure to toxic material include

- Classify wastes prior to incineration.
- Use only those waste materials compatible with the process managed in the unit.
- Note design parameters on feed characteristics and meet the requirements of CEGS 02288: Remediation of Contaminated Soils and Sludges by Incineration.
- Select the appropriate technology for the known or anticipated wastes.
- Use appropriate ventilation controls.
- Designate PPE for workers and handling procedures prior to incineration.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

No unique hazards are identified.

d. Biological Hazards.

No unique hazards are identified.

Chapter 24
Off-Gas Oxidation (Thermal/Catalytic)

24.1 General.

The process of off-gas oxidation is described in the first section of the chapter. The chapter's second portion is a hazard analysis with controls and control points listed.

24-2. Technology Description.

a. Process.

Off-gas oxidation is the incineration of contaminated air or other vapor streams in order to destroy the contaminants before discharge to the atmosphere. A vapor stream laden with volatile organic compounds (VOCs), produced by a soil vapor extraction (SVE) system or a landfill vent system, is blown through a duct system that contains an ignited burner within the duct fed by a fuel such as natural gas or propane. In the thermal application, the heat of the fuel combustion oxidizes the combustible components of the VOC stream in the duct, and the exhaust gas is sent to a stack for discharge. The system is designed to meet a temperature and residence time condition similar to an incinerator.

Catalytic oxidizer units use a precious metal catalyst on a support such as alumina, similar to those used in catalytic converters in automobiles. The function of the catalyst is to lower the required oxidation temperature of the system. The air or gas stream must still be heated but to a lower temperature that allows catalytic oxidation to occur. This saves fuel costs and can reduce the amount of off-gas treatment required (less NO_x is generated). The catalyst is poisoned by the same types of chemicals (lead, coke, and tar compounds) that reduce automotive catalytic system performance. If high concentrations of chlorinated solvents are present, the catalyst support and the duct work may require special construction to cope with the hydrogen chloride gas generated, and scrubbers may be required to remove the acid before the stream is exhausted. See Figure 24-1.

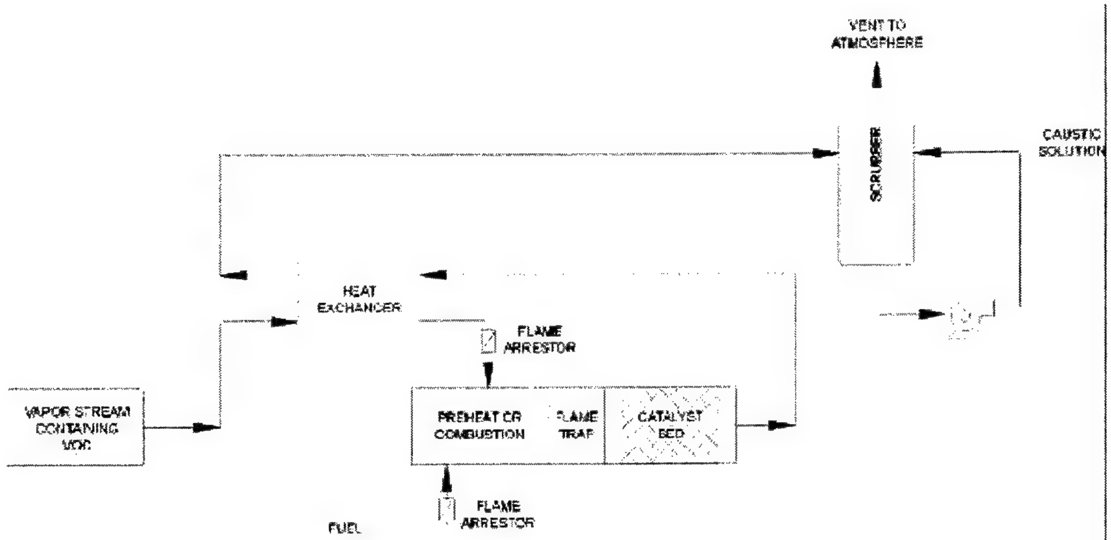


FIGURE 24-1. OFF-GAS OXIDATION (THERMAL/CATALYTIC)

24-3. Hazard Analysis.

Principal unique hazards associated with off-gas oxidation (thermal/catalytic), methods for control, and control points are described below.

a. Physical Hazards.

(1) Fire.
Description: If the BTU value of the waste feed is not controlled and higher than expected BTU value feed is fed into the unit, the temperature of the unit may exceed its design specifications, resulting in damage to the unit and increasing the probability of a release of waste material. Operating off-gas oxidizer systems above the design concentration or temperature may cause auto-ignition and a resulting fire hazard. High-BTU value feeds may generate a fire traveling back into the source.

Control: Controls for fire include

- Use experienced operators and supervisors.
- Audit and apply proper QA/QC to assure work is done as designed.
- Operate the system and waste feed within design parameters.

- Do not allow airflow to exceed the capacity of the system for efficient removal of solids.
- Do not allow temperatures in the primary combustion chamber to exceed 95 percent of the ash fusion temperature (as determined by ASTM E953) of the material being treated.
- Monitor and control the catalyst bed temperatures continuously.
- Incorporate flame traps and control valves into the design to prevent fires from igniting the source.

CONTROL POINT: Design, Operations, Maintenance

(2) Noise Hazards.
Description: Off-gas oxidation units may cause elevated noise levels in the work area due to the operation of air blowers, pumps, and the ignition of fuels within the combustion chamber.

Control: Controls for noise include
- Design and use baffles and insulation to control the transmission of noise.
- Establish a hearing protection program to determine necessary controls and use adequate hearing protection (see 29 CFR 1910.95).
- Use personal electronic communications devices to overcome the noise.
- Establish noise-free areas to provide breaks from the noise, which can cause fatigue and inattention.

CONTROL POINT: Design, Operations

(3) Flammable/Combustible Fuels.
Description: Off-gas oxidation usually requires storage of flammable fuels (e.g., propane or natural gas). Hazards associated with flammable/combustible fuels include the potential for an on-site spill or release of material. The release may cause worker exposure to the vapors generated, or a fire hazard may exist if the material is ignited.

Control: Controls for flammable/combustible fuels include
- Use appropriate tanks (equipped with pressure-relief devices and bermed) to help prevent release of material (see 29 CFR 1910.106).
- Locate tanks in an appropriate location on the site.

CONTROL POINT: Design, Construction, Maintenance

(4) Electrocution.
Description: Since off-gas oxidation units operate electrical systems outdoors, workers may be exposed to electrocution hazards.

Control: Controls for electrocution include
- Verify that drawings indicate the hazardous area classifications as defined in NFPA 70-500-1 through 500-10.

- Use controls, wiring, and equipment that meet the requirements of EM 385-1-1, Section 11.G and NFPA 70.
- Use grounded equipment or equipment with adequate ground-fault protection.

CONTROL POINT: Design, Construction, Operations, Maintenance

(5) Burn Hazards.
Description: Thermal oxidizers operate at high temperatures, which may result in thermal burns to workers.

Control: Controls for burns include
- Use temperature safety control systems to protect people and equipment.
- Use safety barriers to isolate critical sections of the equipment.
- Post signs warning of high temperatures.
- Use heat resistant gloves.

CONTROL POINT: Design, Operations, Maintenance

(6) Transfer Equipment Design.
Description: Improperly designed systems can corrode or dissolve to a point of failure and cause damage to people or the facilities. Workers may be seriously injured or killed under falling or collapsing equipment.

Control: Controls for transfer equipment include
- Use transfer equipment fabricated from materials that are chemically resistant to the chemical being transferred. Chemical resistance charts are available through the National Association of Corrosion Engineers (NACE).
- Consult Hydraulic Institute Standards HI 9.1-9.5 for appropriate materials for pumping various fluids.

CONTROL POINT: Design, Construction, Maintenance

(7) Explosion.
Description: Liquids can condense and collect in the piping systems, resulting in system over-pressurization and explosion.

Control: Controls for explosion include
- Install a knockout tank or drum to collect condensed liquids before they reach vacuum pumps, blowers, or the treatment unit.
- Use containment drip pans or receivers where leaks may occur.
- Install spill and/or leak detection instruments if necessary.
- Implement a routine process system inspection.

CONTROL POINT: Design, Operations, Maintenance

(8) Piping System Leaks.
Description: Workers may be exposed via the inhalation exposure route to a VOC, such as toluene, if leaks occur in the pressurized section of the piping system.

Control: Controls for leaks in the piping system include
- Design the system to operate under a negative pressure (e.g., ducts and piping) for the maximum operating pressure expected.
- Avoid or minimize fugitive emission hazards by designing pressure control mechanisms and appropriate relief systems.
- Install and test fuel systems according to requirements of NFPA 30 (Flammable and Combustible Liquids Code); NFPA 31 (Installation of Oil Burning Equipment); NFPA 54 (National Fuel Gas Code); or NFPA 58 (Standard for the Storage and Handling of Liquefied Petroleum Gases).

CONTROL POINT: Design, Operations, Maintenance

(9) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction activities may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, biological, or radiological hazards.

Control: Control for hazards resulting from predesign field activities include
- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Equipment Entry.
Description: During maintenance and/or repair, workers entering the unit for cleaning, inspection, or repair of equipment may be exposed to waste materials or incomplete combustion byproducts as part of a confined-space entry. Workers may be exposed to an atmosphere containing toxic materials or to one that is oxygen deficient.

Control: Controls for equipment entry include
- Assess hazards at the time of confined-space entry (see 29 CFR 1910.146).

- Wear appropriate personal protective equipment (PPE) such as air-supplied respirator and disposable protective coveralls.

CONTROL POINT: Operations, Maintenance

(2) Toxic Material Exposure (Feed or Byproducts).
Description: During operation of the off-gas oxidation unit, workers may be exposed to waste components/toxic materials in the feed vapor; byproducts of incomplete combustion, such as carbon monoxide; or to airborne toxic materials, including metal acetates, mercury, and chlorine. In addition, toxic byproducts such as dibenzofurans and dioxins may also be generated during the process.

Control: Controls for exposure to toxic materials include
- Classify gaseous waste components prior to oxidation.
- Feed only gaseous waste streams compatible with the process into the unit.
- Note design parameters on feed characteristics. Select technology appropriate for the known or anticipated wastes.
- Train workers in potential exposure hazards and in appropriate PPE.

CONTROL POINT: Design, Operations

(3) Transfer Equipment Design.
Description: Highly chlorinated feed streams may generate corrosive conditions resulting from HCL gas within the off-gas oxidation exhaust stream, causing leaks in the system. The leaks may result in worker exposure via the inhalation/ingestion/dermal exposure routes.

Control: Controls for transfer systems include
- Use transfer equipment fabricated from materials that are chemically resistant to the chemical being transferred. Chemical resistance charts are available through the National Association of Corrosion Engineers (NACE).
- Consult Hydraulic Institute Standards HI 9.1-9.5 for appropriate materials for pumping various fluids.
- Train workers in potential acid exposure hazards and associated hazard controls.

CONTROL POINT: Design, Construction, Maintenance

(4) Toxic Discharge (Catalytic Oxidation Inefficiency).
Description: Poisoning/blinding of the catalyst with high metal and/or particulate loadings in the gas stream may decrease the catalytic oxidation efficiency of the system and increase the discharge of toxic wastes into the work and surrounding areas.

Control: Controls for toxic discharge include

- Monitor and control ash content of the waste feed to prevent excessive particulates from that source.
- Pre-treat air streams adequately to remove particulates using filtration, quiescent zone separation, or washing to prevent excessive particulates.
- Consider the metals content of the air stream in the design to avoid heavy metal poisoning of the catalyst.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

No unique hazards are identified.

d. Biological Hazards.

No unique hazards are identified.

Chapter 25
Open Burn/Open Detonation

25-1. General.

The process, applications, and possible toxic effects of open burn/detonation are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

25-2. Technology Description.

a. Process.

Explosives may be encountered as a part of remedial actions, particularly at military and industrial sites. In many circumstances, the safest or only method for the safe disposal of these materials is by burning or detonation in open pits.

Open burning/detonation uses an excavated and usually bermed burn/detonation pit in which explosives of various classes can be burned and/or detonated. The pit, usually excavated to a depth of 6 to 10 feet, is typically ramped on one side to permit entry. Berms provide added containment while burning or detonating. The material for burning (including burnable explosives) or detonation is pumped or placed into the pit. Then material is ignited or detonated from a distance by electrical or ignitable fuses and/or detonators, signal fuses, torch, or other ignition/initiator sources. Good safety practices dictate electrical ignition whenever possible. In the case of burning explosives, an accelerant fuel, such as gasoline or other readily flammable material, may be poured onto the explosives to easily initiate the burn. Also included for detonations may be a primary explosive to make the explosion more efficient and complete. The contents of the pit are allowed to burn in the confined space until the burning/detonation is complete. See Figure 25-1 for an illustration of the process in simple form.

The pit may be emptied of residue between burnings/detonations or after a sequence of burnings/detonations has been performed. Burning or detonating batches of material in sequence can be highly dangerous since the operator must be certain that all burning/detonation is complete, and no premature ignition sources remain in the pit during reloading of the flammable/explosive wastes.

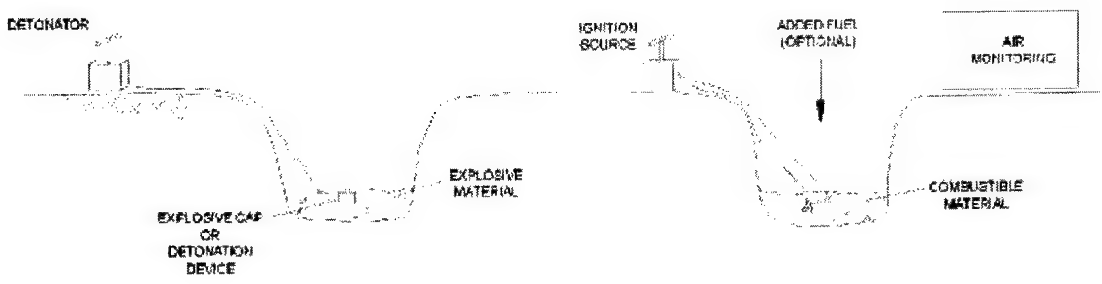


FIGURE 25-1. OPEN BURN/OPEN DETONATION

The operator needs a complete understanding of the age, state, and nature of the explosives or other materials to be destroyed, as well as other chemicals present. Many explosive material properties are radically different when burned or detonated in large masses versus small (e.g., large, burning masses of TNT may self-detonate while small amounts burn safely). An operator should be able to recognize certain metals, oxidizers, or reducers; know when material is partially melted; recognize aged or partially decomposed substances (e.g., picric acid); or a variety of other conditions.

b. Applications.

Explosives include propellants; high and low explosives, many of which will burn and/or explode; various initiators, ignitors, detonators, and accelerants. Included in these categories are dynamite, nitroglycerin, HMX, RDX, TNT, PETN, and Tetryl; mercury and other metal fulminates; styphnates; lead and other metal azides; ammonium nitrate; black powder; picric acid; and derivatives (such as salts) of the above.

c. Toxic Effects.

Most explosives such as TNT, RDX, picrates, HMX, tetryl, dynamite, and lead azides can have toxic effects or produce materials with toxic effects when burned or exploded. Examples of materials released or produced include unreacted explosives such as nitroglycerin and TNT, heavy metals such as lead or silver, salt products, nitrogen oxide, and other nitrogenous residues with potential toxicity.

25-3. Hazard Analysis.

Principal unique hazards associated with open burn/open detonation, methods for control, and control points are described below.

a. Physical Hazards.

(1) Ignition Systems.
Description: Burning ignition systems may not reliably ignite the waste material. The wick or flame used to ignite the waste material may be temporarily extinguished by moisture or wind, only to reignite shortly thereafter. The delay in ignition may cause workers to believe the burning ignition system has failed. As they approach the burn area to investigate, detonation may occur.

Control: Controls for ignition systems include

- Provide proper training and experience for personnel. This is critical.
- Design and construct reliable, remote, intrinsically safe ignition systems as a requirement for operation.

CONTROL POINT: Design, Construction, Operations, Maintenance

(2) Quantity, Type of Explosives.
Description: An explosion may damage the pit construction and injure any workers in the vicinity if more than the design quantity or type of explosives is detonated in one charge.

Control: Controls for quantity and type of explosives include

- Know quantities and types of explosives and never exceed limits.
- Follow control procedures rigorously.
- Evenly distribute explosive wastes. Uneven distribution can create an excessive density of explosive material, resulting in explosive conditions.

CONTROL POINT: Operations

(3) Pit Entry.
Description: Sharp and hot fragments and residue may be present when entering the pit after prior burns or detonations. Workers may also be exposed to potential wall collapse or confined-space entry hazards.

Control: Controls for pit entry include

- Wear appropriate personal protective equipment (PPE).
- Shore walls to prevent collapse.
- Require a structural inspection by a competent person prior to each pit entry.

CONTROL POINT: Design, Construction, Operations

(4) Handling Waste Materials.
Description: Hazards inherent in open burn and open detonation techniques may involve the handling of unstable waste materials, such as unusable munitions and explosive materials. Workers handling these materials face the risk of these materials auto detonating, especially if the explosives have become unstable due to age or other factors.

Control: Controls for handling waste materials include

- Use only persons specifically trained in detonation and disposal techniques to transport and handle materials.
- Consult the Ordnance and Explosive Waste (OE) Center of Expertise (CX), Huntsville, Alabama, prior to any handling or movement of explosive items or of soils/materials significantly contaminated with explosives.

CONTROL POINT: Operations

(5) Structures at or Near Detonation.
Description: One or repeated explosions may cause fragmentation of concrete or cinder block walls of buildings or structures at or near the detonation area, particularly if large quantities of explosive materials are detonated.

Control: Controls for damage to structures nearby include

- Limit the amount of waste materials detonated at any one time based on the known effects of the explosives.
- Divide large volumes of wastes and detonate in a series of smaller explosions.
- Locate the treatment facility carefully so that sensitive structures are not present or nearby.
- Design structures for shelter or containment of the explosions or burnings to adequately withstand the expected use of the system.

CONTROL POINT: Design, Operations

(6) UV Radiation.
Description: During site activities, workers may be exposed to direct and indirect sunlight and the corresponding ultraviolet (UV) radiation. Even short-term exposure to sunlight can cause burns and dermal damage. Hot and humid conditions may also result in heat stress, which can manifest itself as heat exhaustion and heat stroke.

Control: Controls for UV radiation include

- Minimize direct sun exposure by wearing sun hats, long-sleeved shirts, full-length pants, and by applying UV barrier sunscreen.
- Shade work and break areas, if possible.

- Minimize exposure to heat stress conditions by taking frequent breaks, drinking adequate fluids, and performing work during the early morning and late afternoon hours.

CONTROL POINT: Construction, Operations

(7) Predesign Field Activities.
Description: Predesign field activities associated with subsequent construction activities may include surveying, biological surveys, geophysical surveys, trenching, stockpiling, contaminant groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, biological, or radiological hazards.

Control: Controls for hazards resulting from predesign field activities include

- Prepare an activity hazard analysis for predesign field survey activities. EM 385-1-1, Section 1.A provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) Residual or Untreated Material.
Description: If detonation or burning fails to fully neutralize the material, workers entering the burn pit may be exposed to the material. Unreacted material may be carried downwind, exposing workers in the area. Heavy metal primer materials (metal azides and silver compounds) and residual explosive components (e.g., nitroglycerin) may cause heart arrhythmias, headaches, and other physical effects.

Control: Controls for residual or untreated material include

- Remain upwind of the pit during burning and detonations.
- Use PPE as determined by a qualified health and safety professional to enter the pit after burning and explosions. Examples of appropriate PPE include steel shank boots, coveralls to protect from dermal contact, nitrile or butyl gloves if soil handling is expected, and an appropriate air-purifying respirator if fumes or smoke are present.
- Use expertise in detonations and burning, including accelerants or fuels or initiator explosives, to assure the maximum explosive/waste consumption.

CONTROL POINT: Design, Operations

(2) Pit Atmospheric Conditions.
Description: Workers who enter the pit may be exposed to an oxygen deficient atmosphere or to airborne toxic materials.

Control: Controls for pit atmospheric conditions include

- Test the atmosphere within the trench to determine the level of airborne contaminants and the oxygen level prior to entry (see 29 CFR 1910.146).
- Follow confined-space entry protocols, which may necessitate the use of PPE such as an air-purifying respirator equipped with an organic vapor cartridge or a supplied-air respirator.

CONTROL POINT: Operations, Maintenance

c. Radiological Hazards.

No unique hazards are identified.

d. Biological Hazards.

No unique hazards are identified.

APPENDIX A
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GLOSSARY

Annular Space: The space around the outside of the well pipe or casing between the native soil and the well pipe.

Aquifer: An underground body of water capable of producing fresh water at a sufficient rate to be considered a water source. While most aquifers are unconfined (on the sides), they have identifiable floors of impermeable material that define their thickness.

Attrition: Mechanical wear process in which particles rub and abrade against each other removing adhered surface contaminants and contaminated soils.

BTEX: Benzene, toluene, ethylbenzene and xylenes; a group of aromatic hydrocarbons that are present in gasoline and to a lesser extent in diesel fuel. They may also be used individually as solvents. Benzene is a known human carcinogen.

Control Point: The phase of the operation where worker exposure may occur.

DMSO: Dimethyl Sulfoxide: A clear, colorless, odorless liquid that is miscible in water and most organic solvents.

DNAPL: Dense Non-Aqueous Phase Liquids: Organic and inorganic liquids denser than water and high enough in concentration to exceed their solubility in water, thus able to flow down the pores of the soil and sink through groundwater to form a discrete pool or phase beneath the surface of the groundwater.

Ex Situ: "Out of Place": Remediation technologies that require excavation of solids or pumping of groundwater to effectively solve the contamination problem.

Flocculent: A chemical that can bind two or more molecules or complexes so as to form increasingly larger complexes of molecules until the complexes float or sink as large masses.

GCL: Geosynthetic Clay used as a bottom liner in landfills.

HEPA: High Efficiency Particulate Air: Respirator dust filter designed to provide maximum protection against particulate matter.

HDPE: High Density Polyethylene: An inexpensive, readily available plastic liner material for landfills and landfarms. The plastic has good mechanical strength and toughness but is subject to corrosive attack from some organic materials.

Hollow Stem Auger: A drilling method where a series of hollow shafts with a screw-type flight are assembled, typically in five-foot long sections, and turned in a borehole to drill by lifting soil up the flights. The hollow center may be used to drive sampling devices into the soil ahead of the auger to collect undisturbed environmental soil samples.

In Situ: "In Place": Refers to remediation methods that do not require the soil or water to be brought to the surface and hence do not require excavation or pumping.

Leachate: Liquid material that drains from the bottom or sides of a landfill or other waste storage area.

LNAPL : Light Non-Aqueous Phase Liquids: Organic and inorganic liquids less dense than water and high enough in concentration to exceed their solubility in water, thus able to sink through the open pores of the soil to the groundwater and to float on the groundwater to form a discrete pool or phase at the surface of the groundwater.

Mast: The elevated portion of a drill rig that shrouds and protects the drilling flights and drive mechanisms. On most drill rigs, the mast is kept in a horizontal (lowered) position during traveling and when not in use. It is raised into vertical position after the rig has been located at the appropriate drilling spot.

Mud (Drilling Mud): A slurry prepared from bentonite or other fine-grained solid material that may be used as a lubricant for the drilling bits used in borings or well installations or to seal the edges of the boring. Muds are most commonly used in petroleum or other deep drilling. When mud drilling is used in environmental well installations, the mud should be removed to the extent practical before sampling, or a biodegradable mud should be used to prevent the mud from sealing the borehole.

NAPL: Non-Aqueous Phase Liquid: Any organic or inorganic liquid sufficiently high in concentration to exceed its solubility in water and thus exist in the environment as a discrete phase, usually beneath or on groundwater.

Neutron Density Gauge: A measurement device used to determine moisture content in clays and other soil materials. The device contains a radioactive source as part of the measurement mechanism.

NORM: Naturally Occurring Radioactive Materials.

Pathogen: A microorganism that is known to cause diseases in plants, animals, or humans.

POTW: Publicly Owned Treatment Works: A municipal or county water treatment works.

PPE: Personal Protection Equipment: The various pieces of clothing (steel-toed shoes, gloves, coveralls, etc.) and respirator equipment used by personnel for their personal protection from a variety of chemical, physical, radiological, and biological hazards.

Pug Mill: A type of mixing equipment that utilizes a rugged mixing blade configuration to mix high-solid slurries. It may be used to add solids to slurries as a means of thickening.

Pump-and-Treat: A treatment process whereby groundwater is extracted from a contaminated aquifer and treated by some appropriate technology on the surface before reinjection, infiltration, or discharge to a surface water.

PVC: Polyvinyl Chloride: An inexpensive, resilient plastic that has good resistance to many chemicals, frequently used in piping systems and sometimes used as a flexible liner for landfilling and landfarm applications.

RBC: Rotating Biological Contactor: A biological reactor consisting of a series of closely placed rotating disks with a very high total surface area capable of being colonized by a thin film of microbes. The rotating disks are half-immersed in the wastewater stream as it flows through the disks housing allowing the fixed film microbes to be repeatedly soaked in the wastewater while emerging repeatedly into the air, thus allowing the microbes to aerobically degrade the contaminants in the wastewater.

Surfactants: "Surface Active Agents": Chemicals of a large range of types (ionic, non-ionic, zwitterionic) that contain both polar and non-polar molecule regions.

SVE: Soil Vapor Extraction: The process of removing volatile and some semivolatile contaminants by the combined effects of vacuum-increased volatility and vacuum-enhanced mass flow of air into, through, and out of a contaminated unsaturated subsurface zone, thus removing an increased mass of the volatilized contaminants.

SVOC(s): Semivolatile Organic Compound(s): Any of a large group of compounds including the polynuclear aromatic compounds (PNAs) and the polyaromatic hydrocarbons (PAHs) that are low in volatility under normal atmospheric conditions.

TCLP: Toxicity Characteristic Leaching Procedure: An EPA-defined analytical procedure used to classify waste for disposal purposes.

Vadose Zone: The region in the subsurface between the ground surface and the top of the capillary fringe above the water table. This region is characterized by the presence of some liquid water but also some open (vapor-filled) pore spaces.

VOC(s): Volatile Organic Compound(s): Any of a large group of compounds including the monoaromatic (BTEX) and ketones (MEK, acetone, MIBK) that are readily volatile under normal atmospheric conditions.